# Integrated Geospatial Database

# for

# Total Maximum Daily Load Modeling

## Lavaca Bay - Matagorda Bay Coastal Area

Contract No. 582-0-80114

Task (e) Integrated geospatial data base compilation

and

Preliminary Hydrodynamic Modeling

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## Statement of Work

The work presented in this report and on the accompanying data CD-ROM fulfills the requirements stipulated in Task E of the *Geospatial data for TMDL development in Texas* project contract between the Texas Natural Resource Conservation Commission (TNRCC) and the Center for Research in Water Resources (CRWR) of the University of Texas at Austin. (TNRCC Contract No. 582-0-80114). The other major tasks completed under this contract are as follows:

- ??Task B - *Integrated geospatial database compilation* – for TNRCC Basin Group C - Completed in May 2001 by Victoria Samuels (Samuels, 2001)
- ??Task C - *Digital delineation of watershed drainage areas for Basin Group C* - Completed in May 2001 by Victoria Samuels (Samuels, 2001)
- ??Task D - *Development of a GeoObject Model for TMDL* - Completed in August 2001 by Kimberly Davis (Davis, 2000)

Task A involved the submission of progress reports on tasks B, C, D and E. Task E involves the development of a geospatial database for use in TMDL modeling on Lavaca Bay along the Texas Gulf Coast. Some of the compiled data is to be incorporated in a preliminary hydrodynamic model. The purpose of this model is to simulate the movement of water throughout Lavaca Bay, and methods are to be developed for presenting any relevant model results in an ArcView Geographic Information System (GIS). The specific requirements of Task E, as stated in the contract, are given below. In this contract the PERFORMING PARTY refers to the CRWR.

<u>Integrated geospatial data base compilation for Lavaca Bay:</u> The PERFORMING PARTY shall compile an integrated geospatial database for the region surrounding and containing Lavaca Bay. This database shall contain all land areas that drain directly to the Bay, with data layers provided in a common map projection as specified by the TNRCC. The intent of this task is to compile a comprehensive geospatial database for Lavaca Bay in a similar manner to the one completed for Task B in this contract. The database will include those data layers listed under Task B of this contract, with the additional data layers listed below:

(1) Digital elevation model of bay bathymetry
(2) Historical Tidal Records
(3) Available Evaporation/Solar Radiation Data
(4) Historical Precipitation Data
(5) Salinity, Temperature Data Measurements in Lavaca Bay (If Available)
(6) Water Quality Data Measurements in Lavaca Bay (If Available)
(7) Sediment Data for Lavaca Bay (If Available)

These data layers will serve to support models of Lavaca Bay as developed under the Lavaca Bay TMDL project, which will have more specific and comprehensive tasks defined under separate contract. The PERFORMING PARTY will use the data collected for this task in developing a preliminary model for Lavaca Bay, and all output from this model will become part of the deliverables under this contract. This modeling effort will serve to highlight the aspects of the Lavaca Bay system that need to be studied before accurate modeling efforts may be undertaken. Any such model output must be in a format compatible with the ArcView and ArcInfo GIS software. Deliverables for this task will include CD-ROMs of the data layers listed above, CD-ROMs of the preliminary model output data, as well as a report describing the model results and metadata.

The geospatial database is to contain each of the data layers required for Task B of this contract, including:

(1) 30-meter (1:24,000) digital elevation models
(2) 30-meter flow direction grids
(3) 30-meter flow accumulation grids
(4) surface water quality segment hydrography
(5) digital STATSGO (1:250,000 scale) and SSURGO (1:24,000 scale) soils coverages
(6) National Hydrographic Dataset (NHD) 1:100,000 scale digital stream network
(7) additional 1:24,000 scale stream hydrography (where available)
(8) latest available land use layers
(9) point locations of municipal wastewater dischargers
(10) point locations of industrial wastewater dischargers
(11) NWS weather stations/areas of coverage/data
(12) USGS flow gage locations
(13) locations of dams/hydraulic structures
(14) county boundaries
(15) municipal areas (city boundaries)
(16) transportation networks (roads, rails, etc)
(17) Hydrologic Cataloging Unit boundaries
(18) Watershed Data Management (WDM) stations/data
(19) public drinking water supply locations
(20) water quality monitoring stations/data
(21) National Sediment Inventory stations/data
(22) Superfund (National Priority List) Sites
(23) Toxic Release Inventory sites
(24) federal & state congressional/legislative districts
(25) Extra Territorial Jurisdictional areas
(26) National Climatic Data Center (NCDC) precipitation gage locations/data
(27) Solid waste landfill locations
(28) Council Of Government (COG) Regions
(29) surface water rights diversion points
(30) Eco-regions
(31) TNRCC Service regions
(32) TNRCC Class B land application sites
(33) permitted industrial & hazardous waste sites
(34) major and minor aquifer locations/boundaries
(35) latest available vegetation layers
(36) air quality monitoring stations
(37) available TIGER files

The required data is available on the CD-ROM accompanying this report. The data is separated into two sections. The first section contains the geospatial data layers, and the second section contains the layers related to the hydrodynamic modeling. The CD-ROM contents are described in Appendix A. The remainder of this report describes the methods used in developing the geospatial data, as well as the hydrodynamic model setup and preliminary results.

## Introduction

Lavaca Bay is a micro-tidal estuary located along the Texas Gulf Coast near Point Comfort, TX and Port Lavaca, TX. It is a secondary bay that exchanges flow with Matagorda Bay, which in turn exchanges flow with the Gulf of Mexico. The bay is currently listed on the Texas 303(d) list for mercury contamination, low dissolved oxygen, and pathogens. In order to remediate the Bay, the Texas Natural Resource Conservation Commission (TNRCC) must develop and implement a ***T***otal ***M***aximum ***D***aily ***L***oad (TMDL) for each of these three pollution problems. The TMDL development process often involves sampling and watershed/waterbody modeling, and is highly dependent upon the pollutants and the area involved. For example, the main source of mercury contamination within Lavaca Bay is suspected to be derived from the "Dredge Island" created by the ALCOA Alumina & Chemicals facility in Point Comfort. The TMDL modeling for mercury must address the potential contaminant movement from that source location, and therefore must involve hydrodynamic modeling. TMDL modeling for dissolved oxygen must be of a different form, because the main source of the hypoxia is likely to be non-point source pollution. Therefore, the TMDL process for dissolved oxygen must be more dependent upon watershed and runoff modeling. This report describes data and modeling techniques that are applicable to TMDL development for Lavaca Bay.

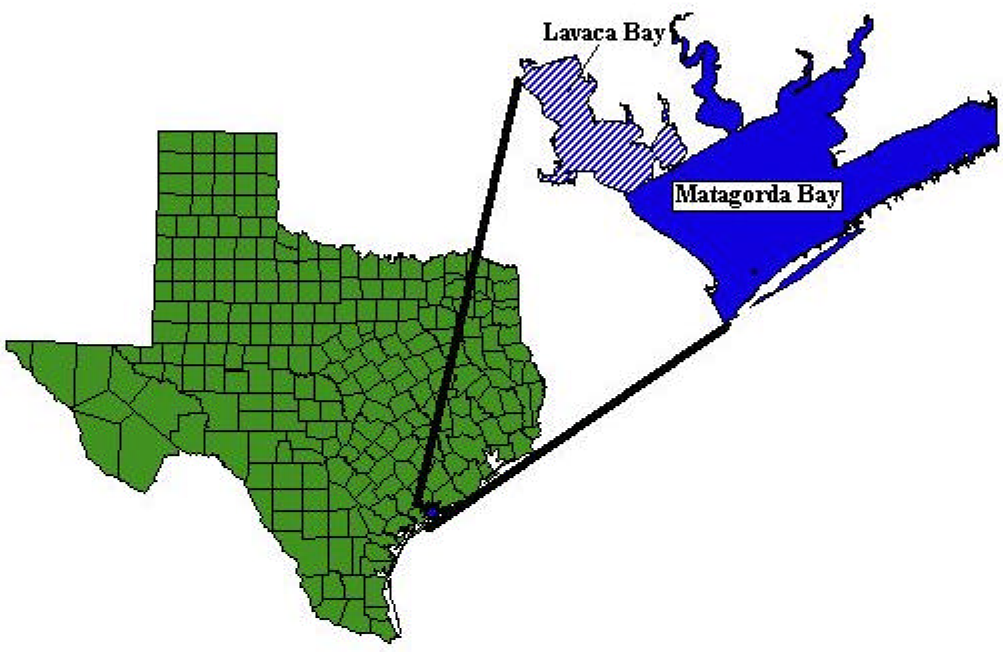



*Figure 1 – Lavaca Bay, located along the Texas Gulf Coast*

The purpose of the geospatial database is to assist in watershed/runoff modeling for Lavaca Bay. This database contains information related to the expected non point source pollutant loads to the Lavaca Bay – Matagorda Bay system. The area of interest is the land area draining to and including Lavaca Bay. This area includes the areas that drain directly to the bay, as well as those areas that drain to rivers flowing into the bay. These areas were determined from a Digital Elevation Model (DEM) of the area surrounding Lavaca Bay, and from the hydrologic data of the area contained in the National Hydrography Dataset (NHD).

**Part 1** of this work describes the DEM and NHD data used in the delineation, as well as the methodology behind DEM based delineation. This methodology incorporates the standard raster-based watershed delineation techniques as well as the specific techniques used for the low-lying Lavaca Bay area. The discussion follows directly from the discussion by Samuels (2001) and documented in completion of Tasks B and C of this contract.

The purpose of developing a preliminary hydrodynamic model of Lavaca Bay is to assist in modeling the movement of mercury throughout the waterbody. This preliminary modeling is useful for determining what types of data need to be collected and/or improved in order to make accurate TMDL determinations. By running the model with various input conditions and comparing the calculated results, it is possible to determine the relative importance of model parameters in predicting water movement. This is useful when developing field sampling strategies, because the group conducting the sampling may have a better idea of what data they should measure and where they should make the measurements. Modeling results under various input conditions may also suggest what types of modeling efforts need to be conducted in order to accurately describe the water movement. For example, some waterbodies may exhibit depth-averaged attributes, where there is not any variation with depth of any constituent of interest. In such cases, a 2-dimensional hydrodynamic model is sufficient to describe the water movement. However, in order to predict stratifications within the water column and horizontally across the bay, a 3-dimensional model is necessary. 3-Dimensional models often require much time and expertise in their development, and when possible 2-dimensional models are commonly preferred. This preliminary modeling effort serves to determine which type of hydrodynamic model is applicable for use on Lavaca Bay.

**Part 2** of this work describes the development of a 3-dimensional hydrodynamic model for Lavaca Bay, linkages between the model and GIS systems, and preliminary results and conclusions drawn from this modeling effort. An extensive discussion of the future modeling possibilities suggested by this work is given at the end of the section.

# Part 1 – Geospatial Database Development

## Watershed Delineation from DEM:

Digital elevation models (DEMs) are essential to watershed delineation because gravity drives water flow over land surfaces. A DEM is an array of elevation values for the ground at a regularly spaced interval (USGS, 1996). The DEMs used for this study were obtained from the National Elevation Dataset (NED). The NED is a compilation of over 50,000 files of DEM data, merged into a seamless dataset with 1 arc-second spacing. The projection of the distributed NED is geographic coordinates with the North American 1983 datum. The elevation values are referenced to the North American Vertical Datum of 1988 (USGS, 1999).

The DEMs used to assemble the National Elevation Dataset are typically produced from cartographic and photographic sources. Cartographic information was gathered from maps of scale 1:24,000 through scale 1:250,000. The topography found on the maps is digitized and then interpolated to take the standard grid format and spacing. Photographic information is processed into the DEM format by manual and automated correlation. The elevations are gathered and these raw elevations are then weighted based on spot heights during an interpolation process to achieve the matrix form and desired interval spacing (USGS, 1996).

Because the NED is composed of various DEMs, the final product contains production artifacts and requires edge matching. Artifacts are removed from the NED by a “mean profile filtering” algorithm that isolates elevation deviations that cause banding in the DEM. The data was then merged together to form the 7.5 minute panels. Small pieces of data were missing from the panels, and a bilinear interpolation algorithm was employed to fill these voids. Any discontinuity caused by merging two DEMs of different quality, scale or source was rectified. Spikes in elevation were replaced by an interpolated value while offsets were corrected by matching the DEM to fit along the edge and correspond with the slope (USGS, 1999).

The NED has a resolution of 1 arc-second, or approximately 30 meter interval spacing, leading to 30 meter cells with unique elevation values. This data is the most accurate currently available for the state of Texas. The NED is retrieved in tile format, in which each tile name is the (x,y) coordinate of the upper left (Northwest) corner of the tile. For example, the upper left corner of dem9530 is at (95? W, 30? N). The elevation information is given in floating point meters. Figure 2 displays the NED in grid form as 30 meter cells as well as the unique elevation values in matrix format.

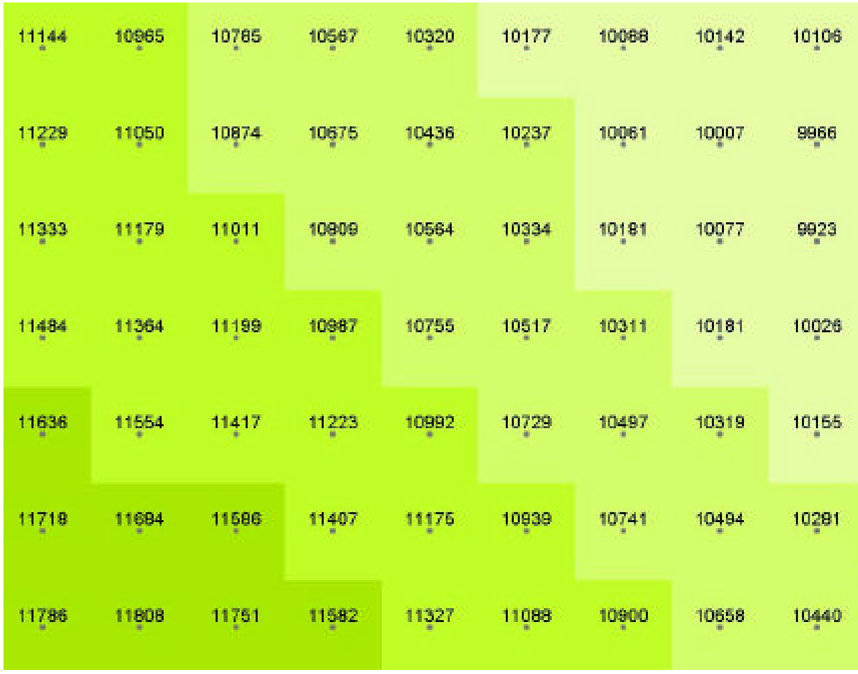



*Figure 2 - Digital Elevation Model with point elevations, units = cm after Samuels (2001)*

In delineating the area draining to Lavaca Bay, 5 NED tiles are used, namely: dem9629, dem9729, dem9730, dem9829, dem9830. The spatial extent of this DEM coverage, as shown in Figure 3, is purposely extensive. Much of this area does not drain directly to the bay, and the 5 tiles were chosen in order to cover all of US HUCs that appear to contribute flow to the bay. The HUC boundaries are watershed boundaries determined from delineations based on 250,000-scale maps. However, in many instances the recently created NHD dataset contains rivers that cross the 250,000-scale map based HUC boundaries. When watersheds are delineated from a 30m DEM, the boundaries often do not exactly coincide with those created from the 1:250,000 scale maps. For this reason, the watershed delineation process was carried out on the 5 NED tiles. The NHD outlines of Lavaca Bay and Matagorda Bay were used as the delineation sources. (See Appendix B for a description of the watershed delineation process).

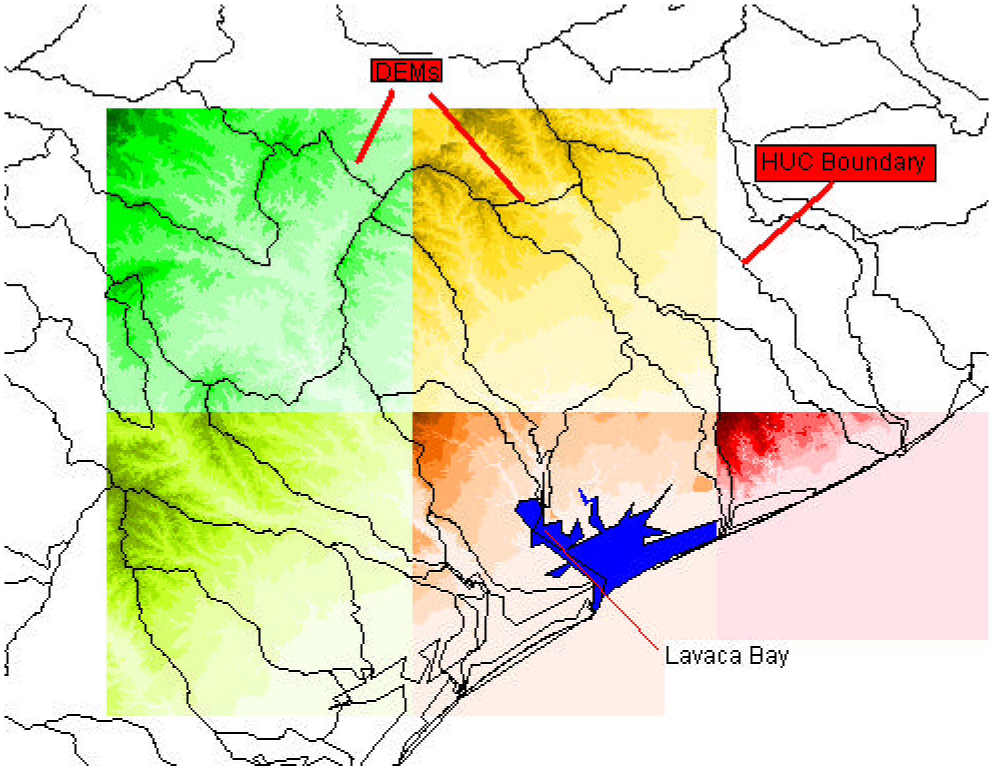


*Figure 3 – NED Tiles covering the HUCs around Lavaca Bay*

After delineating with the 5-tile DEM, the DEM was clipped based on the watersheds draining to the bays. When clipped, the resultant DEM had a cell size of 28.928 meters, which is a standard default grid size for ArcInfo. To convert this into a 30m grid, I used the resample function in ArcInfo, accepting NEAREST as the default calculation method:

Grid: dem = resample(clipdem, 30)

The resulting DEM consisted of 5,305 rows and 4,347 columns (23,060,835 cells), which is approximately a 75% reduction from the 7746 row, 13170 column 5-tile DEM. In order to include the waterbody area in the clipped DEM, it was necessary to merge the watershed theme with a polygon theme consisting of numerous rectangles. These rectangles cover areas that drain to Lavaca Bay and/or Matagorda Bay but were not identified as such in the watershed delineation process. The areas were mistakenly identified as inland catchments because the DEM was not filled before delineating the preliminary watersheds. Addition of the rectangles accounts for the rectangular appearance of the clipped DEM at its lower right corner (see Figure 4). The effect of this rectangular shape on subsequent delineations is expected to be minimal because the focus of the delineations is to determine those areas that drain to Lavaca Bay. The rectangular sections of the clipped DEM are to the South East of Lavaca Bay, closer to the Gulf of Mexico. It was assumed unlikely that flow from these regions enters Lavaca Bay, except possibly through open-water exchanges between the bay and Matagorda Bay. This assumption was proven correct when the watersheds were delineated accurately.

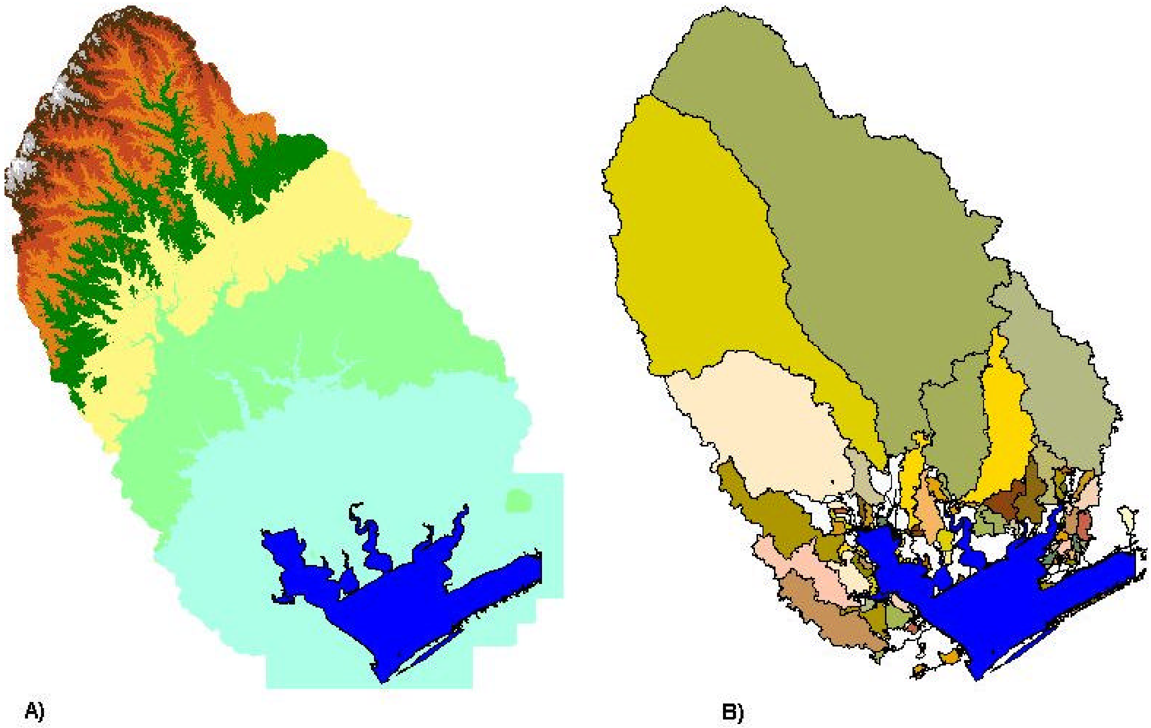


*Figure 4 – 5-tile DEM Processing Results – A) Clipped DEM, B) Delineated watersheds*

The preliminary watersheds delineated from the 5-tile DEM, as shown in Figure 4 B, are not correct. In many locations, boundaries are delineated across regions through which NHD streams flow. The delineation also suggests that other areas do not flow into the bay system, that they were inland sinks (See discussion of "rectangles" on the previous page"). These errors were corrected by "burning" selected NHD and hydrographic reach data into the DEM. Also, the original DEM has elevation values for locations within the waterbodies. This causes the ArcInfo program to attempt to delineate watersheds within the waterbodies. To fix this source of error, the DEM cells within the waterbody were given a NODATA value. This also allows for the delineation of shoreline watersheds. This type of watershed consists of areas that contribute flow directly to the waterbody across the waterbody shoreline, without first contributing flow to a river. (See Appendix C for a description of the stream burning and shoreline catchment determination process).

The following ArcInfo commands convert the DEM cell elevations within the waterbodies to NODATA values:

1. Grid: temp = isnull(waterbodies)
2. Grid: mult = setnull(temp == 0, temp)
3. Grid: demmod = mult * dem

The "waterbodies" grid was created when the ArcView "Convert to Grid" function was applied to the Lavaca.shp theme. This theme contains a single polygon in the shape of the Lavaca-Matagorda Bay system. It was created from the merger of NHD waterbodies and temporary polygons covering the spatial extent of the islands within Lavaca Bay. (See

Appendix D for the shapefile description). The waterbodies grid was created at the same scale and extent as the dem grid, and each cell corresponding to a part of the waterbody was assigned the value "1" while non-waterbody cells have the NODATA value. The "Temp" grid has cells with the value "1" that are NODATA cells in the waterbodies grid, and all other cells have the value "0." The "mult" grid has cells with the value "1" as in the "Temp" grid, and NODATA value cells where the "Temp" grid has the value "0." Therefore, the "mult" grid contains the NODATA value for the waterbody cells, and all other cells are "1." When this grid is multiplied by the DEM, the result is that the waterbody cells maintain the NODATA value, and all of the remaining cells take the value of the original DEM cells.

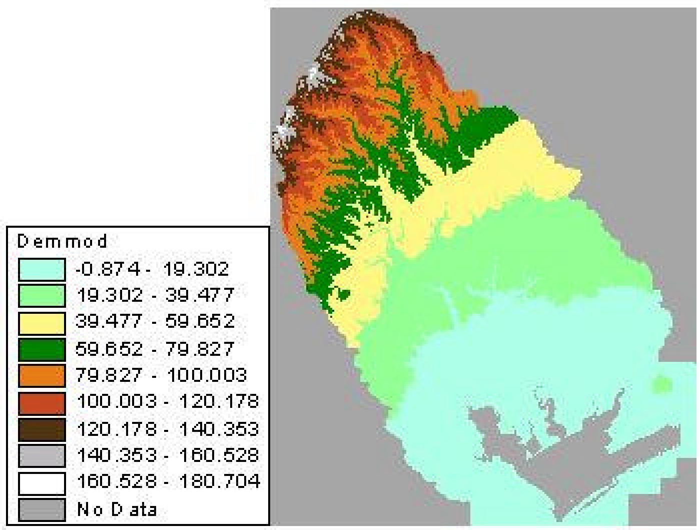



*Figure 5 – Demmod, with NODATA Values assigned to waterbody cells*

Following the procedure used by Samuels (2001), the NHD stream-river arcs were used in creating the burned DEM. These arcs are derived from the NHD route.drain coverages for the study area. The NHD is classified and packaged based on the HUC boundaries and numbers. The NHD units used in this work are: 12100101, 12100102, 12100204, 12100401, 12100402, and 12100403. The stream-river arcs were extracted from the other arcs with the ArcView Query tool. All NHD artificial paths and canal-ditches were excluded. (Figure 6). Also excluded were the waterbody shorelines and double-line rivers. This suggested that the rivers draining into Lake Texana do not ultimately drain into Lavaca Bay, as indicated by the entire NHD. As such, the NHD streams (Figure 6B) are insufficient to accurately delineate the Lavaca Bay drainage areas. However, it is also impossible to use the entire NHD, because the presence of canals and artificial paths causes the network to form loops. Loops pose difficulties in DEM based watershed delineations because the computer must decide which path the water will follow.

To avoid loops while maintaining the implied drainage patterns suggested by the NHD, the major arcs draining directly to Lavaca Bay were grouped together in the *TOBURN.shp* data layer. This layer consists of the major arcs from the *hydro_arc_g.shp* data layer (available on the accompanying CD-ROM). This data layer is a section of the 1:24,000 scale hydrography layer published by the Texas General Land Office.

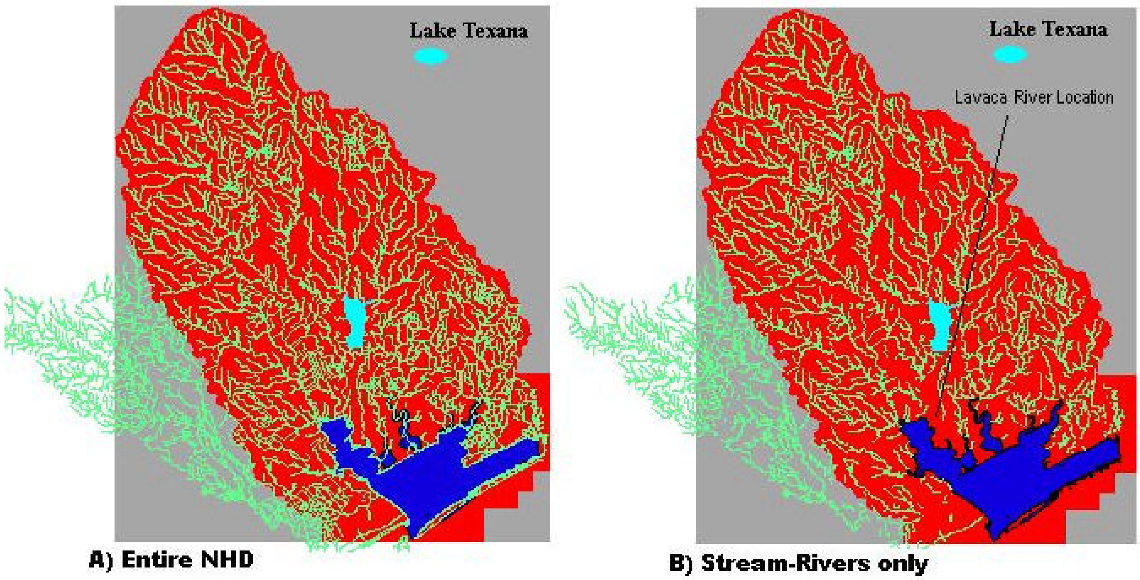



*Figure 6 – NHD Processing with DEM extent shown for reference – A) Entire NHD, containing many loops and canals on which delineations are impossible, B) Only the NHD stream-rivers, without loops. However, the double line rivers were also removed, and the Lavaca River downstream of Lake Texana is not included.*

The hydro_arc_g.shp theme contains only the largest rivers in the study area. Those rivers that drain into Lavaca Bay were selected and converted to a temporary shapefile. This temporary file was modified by adding the artificial path through Lake Texana and one line of the double-line Lavaca River as published in the NHD.

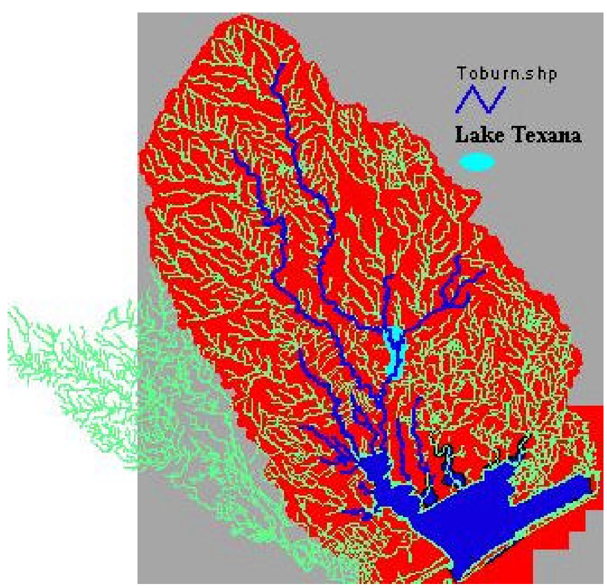



*Figure 7 – Toburn.shp (blue arcs) created from hydro_arc_g.shp and parts of the NHD. These arcs represent the most significant river inflow sources to Lavaca Bay, based on drainage area.*

The Toburn.shp theme was converted to the Toburn grid using the ArcView "Convert to Grid" function. It is equivalent in scale and extent to the demmod grid. The cells corresponding to each arc were given the value “0” and the other, non-arc cells have a NODATA value. The process of burning the Toburn.shp theme into the demmod grid was carried out using the ArcInfo grid statements:

1. Grid: temp1 = isnull(toburn)
2. Grid: temp2 = temp1 * 2000
3. Grid: Burndem = demmod + temp 2

The “temp1” grid contains the value “1” for all non-arc cells, and the value “0” for all arc cells. The “temp2” grid is the elevated grid, with the non-arc cells 2000 units greater than the arcs, which have a 0 value. The “2000” elevation was selected arbitrarily – the only requirement is that it is larger than the highest elevation in the DEM. (In this case, the highest DEM elevation is 180m). The Burndem is simply the sum of the demmod grid and the elevated grid. The non-arc cells of the Burndem grid have values 2000 meters greater than the values in the demmod grid. The arc cells of the Burndem grid have identical values as the corresponding cells in the demmod grid.

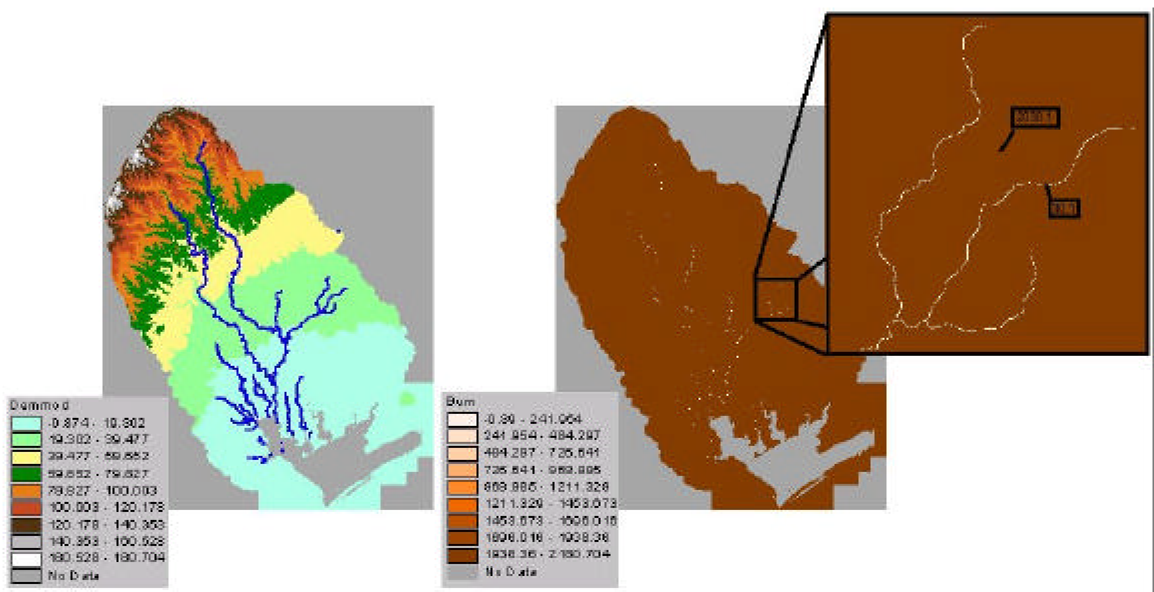



*Figure 8 – Results of the DEM Burning process*

The Burndem grid was then filled, and from this filled grid, the flow direction and flow accumulation grids were generated. The ArcInfo commands are:

1. Grid: Fill = Burndem Filldem SINK
2. Grid: Fdr = Flowdirection(Filldem)
3. Grid: Fac = Flowaccumulation(Fdr)

The watersheds are delineated based on the flow direction grid (fdr) and a source grid. The source grid describes the locations for which watersheds are to be determined, and any cell that is upstream of a point on a source grid is given the gridcode of that source grid point. The source grid used in this work is a combination of the *Toburn.shp* and the outline of the Lavaca – Matagorda Bay system. This outline was created by using the Shapearc function in ArcInfo:

Arc: shapearc waterbodies.shp outline LINE

The “shapearc” function converts an ArcView shapefile into an ArcInfo coverage. In the above command, the created coverage is “outline,” and the coverage type is specified as “LINE.” The outline coverage contains numerous individual arcs, which were dissolved into one arc with the ArcView Geoprocessing extension. This one arc was then merged with the Toburn.shp theme to create the *drainage.shp* theme. Next the  tool was used to split the single waterbody outline into various segments, with the endpoints of the segments corresponding to the endpoints of the rivers in *Toburn.shp*. Finally, all of the arcs in the *drainage.shp* theme were assigned a unique ID for use as a gridcode in the watershed delineation.

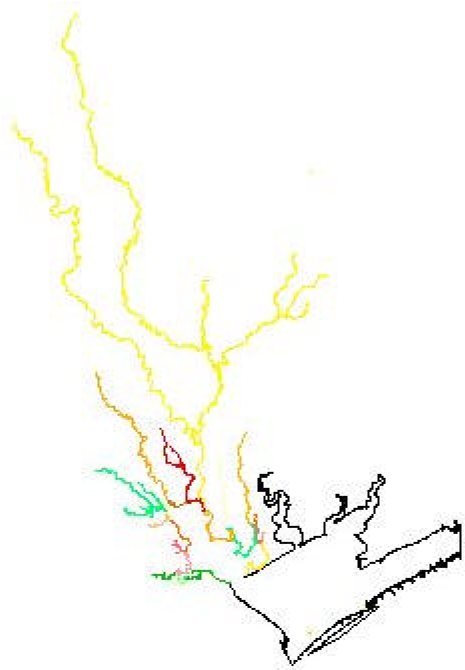


*Figure 9 – Drainage.shp theme – each color is a separate segment from which a watershed will be delineated.*

The watershed delineation was performed with the following ArcInfo command:

Grid: wtrshd = watershed(fdr, Drainage)

“Drainage” is the raster representation of the *drainage.shp* theme, and it was created with the ArcView “Convert to Grid” function. Once delineated, the wtrshd theme was converted to a polygon shapefile, *wtrshd1.shp*. This shapefile contains the watersheds that drain to a river entering the Lavaca Bay-Matagorda Bay system, and the watersheds that drain directly into the system through the bay coastlines. This file was then copied, and the watersheds were dissolved based on to which bay (either Lavaca Bay or

Matagorda Bay) they contributed flow. This theme was saved as *wtrshd2.shp*. This shapefile contains only two polygons. These polygons represent the entire watersheds for Lavaca Bay and Matagorda Bay.

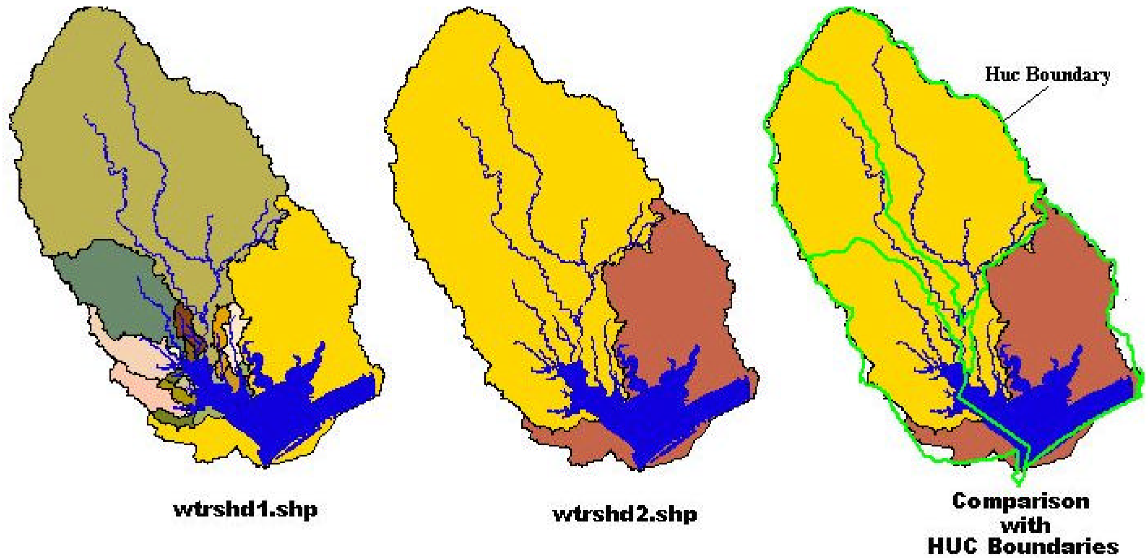



*Figure 10 – Delineated Watersheds for the Lavaca Bay – Matagorda Bay Area.*

In general, the delineated watershed boundaries correspond well with the older HUC boundaries that were delineated from the 1:250,000 scale maps. The greatest discrepancies between the two boundaries occur closer to the Gulf of Mexico, where the terrain is nearly flat. Watershed delineation is difficult in such flat areas.

The *study_area.shp* theme was created by adding a 100m buffer to the shapefile *dem.shp*. This shapefile was created by masking the DEM grid (dividing the DEM grid by itself so that all values are either "1" or NODATA) and converting the resulting grid to a shapefile. This *dem.shp* theme is a single polygon covering the watersheds draining to Lavaca Bay and Matagorda Bay. The 100m buffer was created by applying the "Create Buffers" functionality within the ArcView 3.2 software. This functionality expands the border of the polygon to which it is applied. In this instance, the Lavaca Bay and Matagorda Bay watersheds were expanded to include all land within 100m of the watershed border defined by the DEM based watershed delineations. The 100m expansion covers approximately 3-DEM grid cells and is included in order to minimize any errors associated with raster-based watershed delineation in coastal areas. The *study_area.shp* theme was used to clip all of the geospatial data layers included in the database.

# Part 2 – Hydrodynamic Modeling

For this study, a preliminary hydrodynamic model of Lavaca Bay was constructed with the **E**stuaries and **L**akes **CO**mputer **M**odel (**ELCOM**), created by Dr. Ben Hodges and distributed by the Centre for Water Research (CWR) at the University of Western Australia***. ELCOM is a 3D hydrodynamics model that involves Coriolis forcing and various turbulence modeling methods in solving hydrostatic, Bousinesq, and time-dependent Reynolds Averaged Navier-Stokes (RANS) equations for fluid flow. The model has been recently applied to predicting internal wave propagation in Lake Kinneret in Israel, as well as used in other studies in Australia, Greece, Germany, and Japan. Along with this project, US applications of the model include attempts to describe the estuarine dynamics of Jamaica Bay in New York, as well as the flow patterns in Lake Travis in Central Texas. The data layers provided here were used in ELCOM runs that are designed to demonstrate the model's potential for determining bay circulations. The modeling is preliminary only, and the results have not been verified with field data. One outcome from this project is a method for displaying the ELCOM results as raster grids in ArcGIS or ArcView.

ELCOM was the selected for use on this project because it has demonstrated remarkable accuracy in previous applications for predicting water movement (Hodges et al, 2000). The in-depth review of existing 3-dimensional hydrodynamic models (1-Ward and Benaman, 1999; 2-Ward and Benaman, 1999) did not suggest a more suitable, readily available model. Also, the linkage between the ELCOM model and the GIS software packages, although not initially existent, was thought to be achievable because of the format in which both programs store bathymetry data.

### Bathymetry Data for Lavaca Bay

Bathymetry data was obtained from the GEODAS data package (NOAA, 2001), available from the National Geophysical Data Center. This branch of the National Oceanic and Atmospheric Administration (NOAA) strives to provide global environmental and satellite data for use by scientists, politicians, and the general public. The GEODAS package is a formalized database of environmental data, including bathymetry data and soundings collected and reported since 1930. The program output may take on various forms. For this modeling effort, the program generated a text (.txt) file that contains the latitude, longitude, and water depth of every sounding available in the database.

This text file was converted into a database file (.dbf) in Microsoft Excel, and it was then imported as a table in ArcView. Using the “Add Event Theme” function, the *bath_points.shp* theme was created. This theme consists of a point for each sounding location, and the location is attributed with the reported sounding depth.

*** Dr. Ben Hodges is now an Assistant Professor of Civil Engineering at the University of Texas at Austin

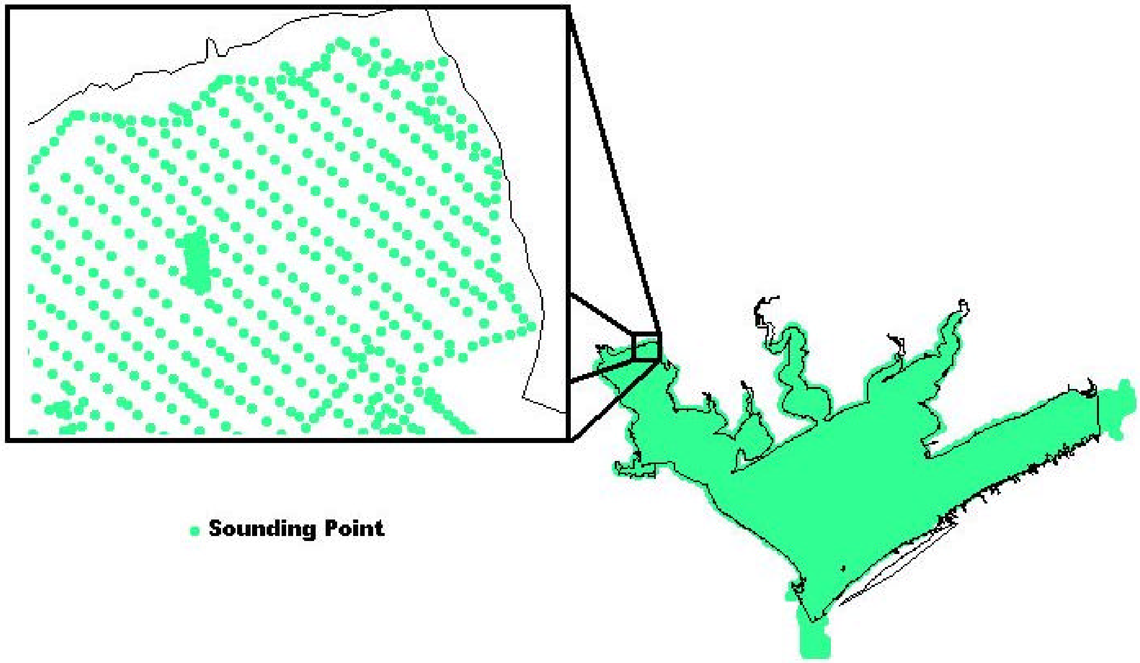



*Figure 11 – Sounding points in the bath_points.shp theme*

Nearly 54,300 soundings are included in the *bath_points.shp*, and these points were derived from numerous surveys. The consistency of these surveys was not investigated. Of these 54,300 soundings, 16,200 are located within Lavaca Bay. Bathymetry grids were interpolated from these 16,200 Lavaca Bay soundings. On average, there is 1 sounding for each 50,000 $m^2$ area of the bay (corresponding to a cell 225m x 225m in size).

The interpolation was performed with the "Interpolate Grid" function available with the ArcView Spatial Analyst Extension. The grid is developed with the Inverse Distance Weighted (IDW) interpolation technique, which makes use of the points closest to a given location in order to estimate the value of the elevation at that location. The bathymetries used here were created by accepting the ArcView IDW default parameters. These parameters are: "Nearest Neighbors, "12" neighbors, "2" power, and "no barriers."

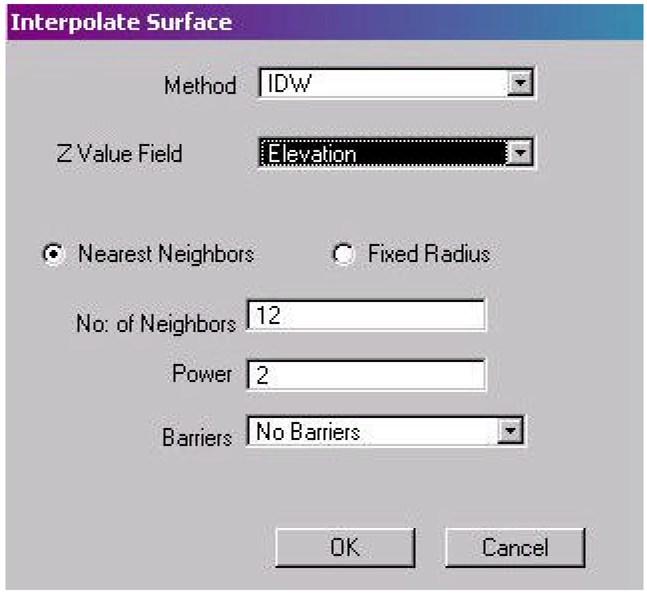



*Figure 12 – ArcView Surface Interpolation Input Window (with default parameters)*

The "Nearest Neighbor" method and the "12" specified neighbors requires that the interpolation at any point is driven by the 12 measurements nearest to the given point. The "2" power determines the weighting applied to each of the neighbors, and it describes the relative importance of a given measurement in an interpolation. With higher powers, the nearest neighboring points are given more influence in the interpolation scheme than are the farther neighboring points. The "No Barriers" specification means that the interpolation is not terminated at any set boundary other than the boundary of the overall grid. For these interpolations, this boundary was an arbitrarily defined rectangular polygon theme that encompassed the entire area of Lavaca Bay. The cell size of the interpolated grid is also determined by the user.

The interpolated grid was clipped by a polygon theme (Figure 13). This theme was itself clipped from the *waterbodies.shp* theme. The portion of Matagorda Bay that was included in the clipped grid was arbitrarily chosen, without any consideration for hydrodynamic influences.

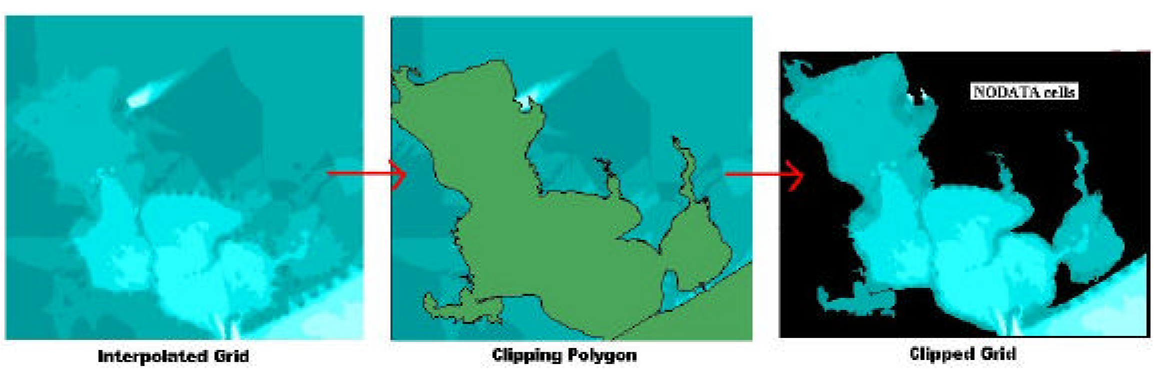



*Figure 13 – Clipping the interpolated grid with a Lavaca Bay polygon theme*

Grids were delineated at 10m, 50m, 100m, 150m, 200m, and 250m cell sizes. The grid shown in Figure 13 is the bathymetry from the 10m grid. Even at this fine resolution, it is obvious that the bathymetry does not include any of the ship channels within the bay. The existence of the ship channels may drastically affect the circulation patterns within the bay, and to test this hypothesis a sample ship channel was burned into the 250m, 150m, and 100m bathymetry grids.

The location, depth, and width of the ship channels was approximated based on comparisons between the locations of spoil islands within the NHD, the bay outline, and a *Fish-n-Map Co.* map of Matagorda Bay (Provided by Dr. Paul Montagna of the University of Texas Marine Science Institute). The new line theme, *ship_channel.shp*, was buffered to a width of 75m, so that the total channel width is 150m. Channel depths were obtained directly from the *Fish-n-Map Co*. map. More accurate representations of the ship channel are likely available from the U.S. Army Corps of Engineers, the TNRIS system, and the Texas General Land Office. However, such more accurate representations were not used in this preliminary project. The purpose of this project was to assess the effect of including a ship channel in the Lavaca Bay model.

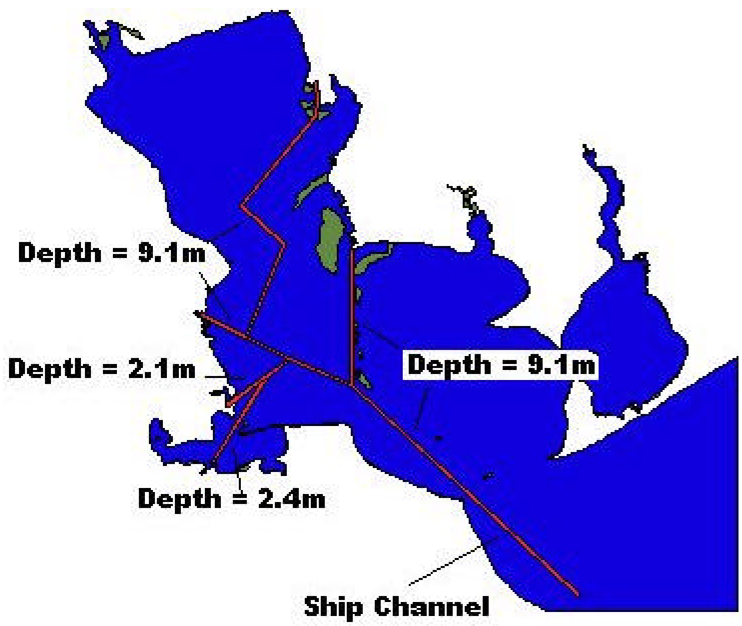



*Figure 14 – Ship Channel Locations and Depths (Approximate)*

The ship_channel.shp was converted to grid themes of 100m, 150m, and 250m cell sizes. The grid values were the depths of the channels, and the grid extent was equivalent to that of the bathymetry grids. The ship channel had to be re-buffered to an additional 100m (i.e a total width of 350m) in order to obtain a continuous raster channel at the 250m grid scale.

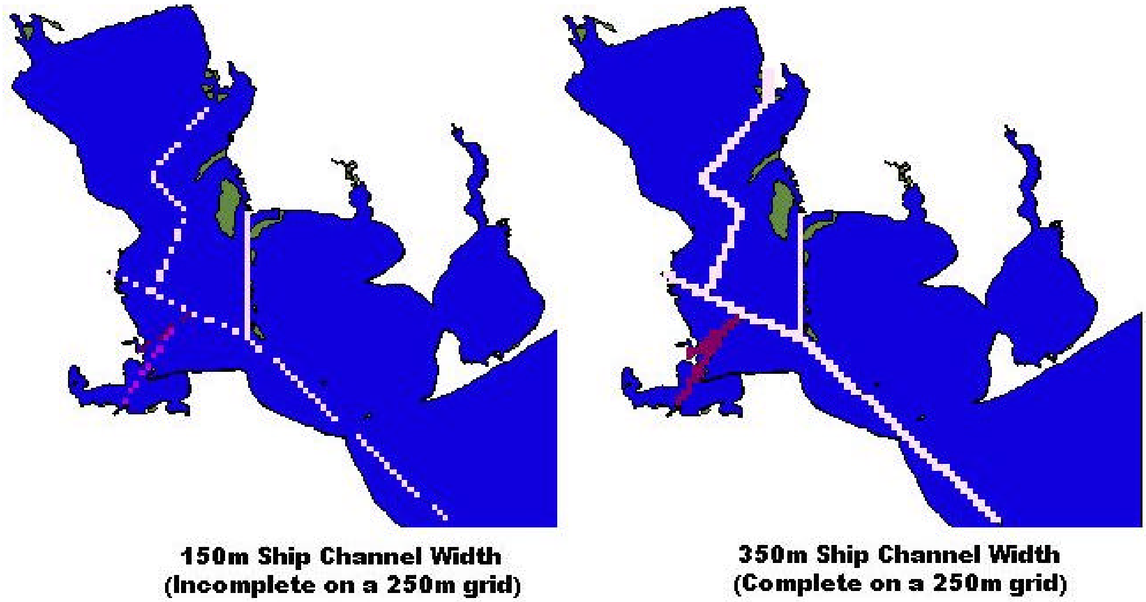



*Figure 15 – Raster Representations of bay ship channels (NODATA Cells are transparent)*

The ship channel bathymetries are incorporated into the bay bathymetries by the following set of ArcInfo commands:

1. Grid: tempXYZm = isnull(channelXYZ)
2. Grid: multXYZm = tempXYZm * bathXYZm
3. Grid: addXYZm = con(isnull(channelXYZ), 0, channelXYZ)
4. Grid: bathXYZm_channel = addXYZm + multXYZm

Where "XYZ" is the 3 digit number corresponding to the grid cell size. The "channelXYZ" grid is the grid of the ship channel as shown in Figure 14. "TempXYZm" is a mask grid where the channel cells have the value "0" and all other cells have the value "1." "BathXYZm" is the bathymetry grid generated from the *bath_points.shp* theme. "MultXYZm" contains the bathymetry values for all non-channel cells. The channel cells have the value "0." "AddXYZm" contains the value "0" for all non-channel cells, and the channel bathymetry for all channel cells. The "bathXYZm_channel" is the bathymetry grid with the channel included.

The final step in the ELCOM bathymetry preparation process is to identify the land cells and the open boundary cells. The open boundary cells are those cells upon which the known tidal heights are applied. In this model, the open cells are those cells along the South East corner of the grid, corresponding to point within Matagorda Bay. In ELCOM, the model user has the option of specifying the grid values that signify land cells and open boundary cells. For this project, the values "9999" and "8888" were used, respectively.

In order to assign the open cell values, the cells must be identified in a grid. This is accomplished by creating a line theme that extends over only the open value cells. The "open cell" grid is created by converting the line theme to a grid of cell size and extent equal to that of the bathymetry.

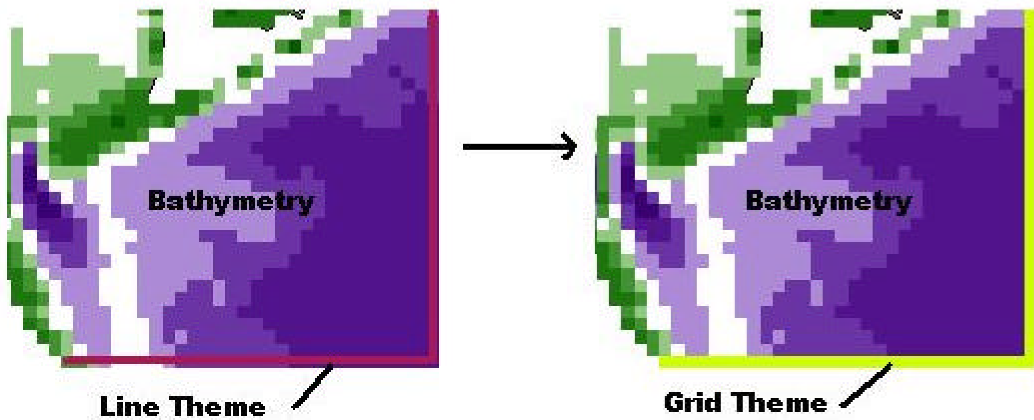



*Figure 16 – Open cell location by converting a line theme to a grid (NODATA cells are transparent)*

Once the "open_cellXYZm" theme is created, the ELCOM bathymetry grid is generated with the following ArcInfo commands:

1. Grid: tempXYZm = isnull(open_cellXYZm)
2. Grid: multXYZm = tempXYZm * bathXYZm_channel
3. Grid: addXYZm = con(temp == 1, 0, 8888)
4. Grid: openXYZm = addXYZm + multXYZm
5. Grid: XYZm_channel = con(isnull(openXYZm), 9999, openXYZm)

"XYZ" is the 3 digit number corresponding to the grid cell size. The "bathXYZm_channel" grid is the bathymetry grid including the channel. This process also works on other bathymetry files that may or may not include the channel. The final result, XYZm_channel, must be exported to an ASCII raster text file before it can be incorporated in ELCOM. Sample ELCOM bathymetry grids are available on the TASK E data CD accompanying this report.

## Formatting GIS Bathymetry Grids for Use in ELCOM

ELCOM receives bathymetry input as a text file, and this text file is used in the ELCOM pre-processing program. This program "constructs" the 3-dimensional spatial domain over which the hydrodynamic calculations are made. A section of the bathymetry input file *250m_channel.txt* is given in Appendix E. This is the input file used in simulations including the ship channel. The sample only includes part of the actual bathymetry data.

All ELCOM bathymetry files contain a specific set of information in a specific arrangement and order. As shown in Appendix E, the file first contains information related to the specific model setup (i.e. title, user name, date, etc), followed by information describing the extent and geographic location of the bathymetry grid. The penultimate data specified by the file are the sizes of the 3-dimensional grid cells included in the model. ELCOM grid cells may have different sizes in each of the three principal directions (X, Y, and Z), and cell heights (Z values) do not have to be uniform across the depth of the waterbody. The user can tailor the vertical size of the grid cells in order to obtain the best resolution for the processes to be modeled.

The final section in the bathymetry input file specifies the bathymetry values for the waterbody. Specifically, a bathymetry value is included for each cell in the (X, Y) area domain. These values are listed by row, and are separated by spaces (space-delimited format).

```
! ------------------------------------------------------------------------- !
! x in rows (increasing down), y in columns (increasing across)             !
 BATHYMETRY DATA
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
```

*Figure 17 – Section of Bathymetry Data Input file for ELCOM (Values shown represent land cells)*

Unlike many hydrodynamic models, ELCOM places the grid origin at the upper-left corner, with the row number increasing downward and the column number increasing across from left to right. This, and the space-delimited nature of the input data allows for easy conversion of GIS raster bathymetry data into ELCOM format. GIS raster data is formatted in a similar manner to the data required by ELCOM.

GIS grids may be exported into an ASCII-raster format using the export functions in ArcView and ArcGIS. The exported files are text files with the ".asc" extension. These files contain all of the information used by the GIS system in order to properly orient the grid to a specific geographic location, as well as the value stored in each individual grid cell. As with the ELCOM bathymetry input file, the exported GIS grids use the upper left corner of the spatial domain as the domain origin.

```
ncols         96
nrows         89
xllcorner     1825214.78276
yllcorner     7161459.095
cellsize      250
NODATA_value  -9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
```

*Figure 18 – Section of Exported GIS Bathymetry Grid showing spatial reference information and some bathymetry values*

The exported GIS grid ".asc" file may be combined with a user-specified input text file in order to produce a properly formatted ELCOM bathymetry input file. The user-specified input file must contain the ELCOM model setup information, as well as the Z-height values to be included in the model calculations. The size of the grid cells in the X and Y directions is determined directly from the ".asc" file, as is the number of rows and columns included in the grid. The text file combination is carried out by the stand-alone Visual Basic program ***Bathymetry.exe*** created by Jordan Furnans of CRWR.

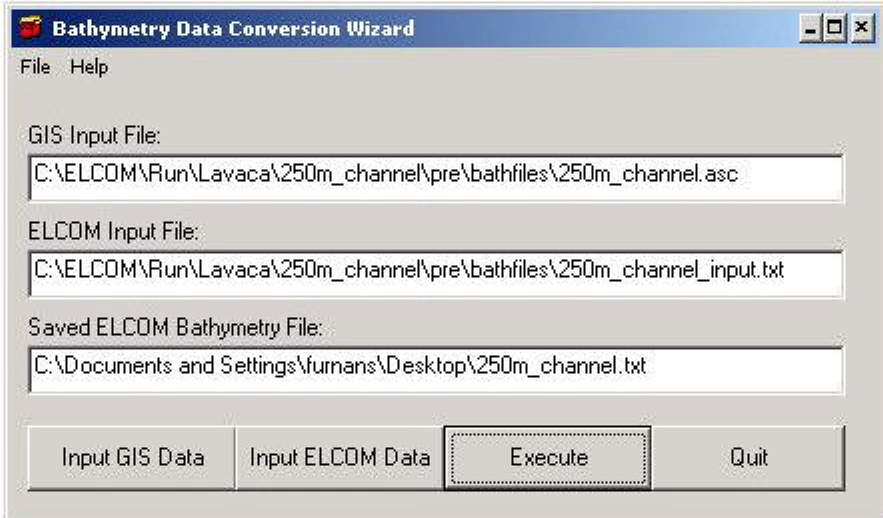



*Figure 19 – Bathymetry.exe interface for converting GIS ".asc" files to ELCOM Bathymetry files*

The ***Bathymetry.exe*** program works by extracting data from the GIS ".asc" file and the user-defined ELCOM input file, and then combining these extractions in the proper order. The output is a new text file suitable for use in the ELCOM pre-processing program. The program user can define the name and storage location of the new text file (Figure 18). The sample ELCOM bathymetry file *250m_channel.txt was* generated with the ***Bathymetry.exe*** program with the *250m_channel.asc* and *250m_channel_input.txt* given in Appendix E.

## Preliminary ELCOM Simulation Results

ELCOM simulations were conducted with three distinct input scenarios:

1. 250m bathymetry, without ship channel, without Lavaca River inflow
2. 250m bathymetry with ship channel, without Lavaca River inflow
3. 250m bathymetry with ship channel, with Lavaca River inflow

These simulations are designed to investigate the effect of the ship channel and Lavaca River inflow to the circulation patterns within Lavaca Bay. The results presented in this work are meant to serve as examples of the type of output and information the ELCOM model can provide.

ELCOM output is processed with the MATLAB software package, and as such users familiar with ELCOM may develop their own methods of displaying and classifying the model results. For this project, plan view velocity vector plots were generated in order to demonstrate surface and depth-averaged circulation patterns. The depth-averaged results are calculated within ELCOM as the average of calculated results at depth for each surface grid cell. Each simulation was run with a steady 10 ft/s wind from the South East

(160 degrees from North) and tidal forcing as described from measurements at Port O'Connor at the Southern tip of Matagorda Bay. For simulations without the channel, the z-dimension for each of 10 cell layers was 0.5m. This vertical grid cell size was increased to 1.0m per cell with the addition of the ship channel. When inflows were included in the model, the stream flow data was calculated from the USGS gage station data for rivers flowing into Lake Texana, upstream of Lavaca Bay. These input parameters are not intended to simulate any particular event or time period, and the results are only useful in making comparisons between the different input scenarios. Each simulation was run for 1000 iterations at a 15-minute time interval, for a total simulation time of 10.4 days.

Output was generated at every $10^{th}$ time step, therefore each simulation generated 100 datasets. For each dataset, the model calculated u and v velocities, which were combined within MATLAB to produce arrow plots. Each arrow represents a velocity vector for the water contained in the grid cell. The length of the arrow is proportional to the velocity of the water movement, and the direction of movement is indicated by the direction of the arrow. For each simulation, the 100 output plots were combined into two QuickTime movie files. These files provide a visual indication of the circulation patterns in the Bay, as well as how these patterns change over time. The first Quick Time movie for each simulation displays the calculated ELCOM results for each grid cell. The second movie displays the results for every second grid cell, which makes the circulation patterns easier to view. All of the simulation movies are available on the Task E data CD-ROM.

The velocity plot shown in Figure 20 was generated from the first simulation, which did not include the ship channel or inflow from the Lavaca River. At this particular time, most of the movement within Lavaca Bay occurs at the interface with Matagorda Bay. This is an example of an ebbing tide. The plot shown in Figure 21 is the same time slice as shown in Figure 20, but with the channel included in the simulation. A comparison of the two figures indicates that the channel has a significant affect on the depth-averaged velocities in Lavaca Bay. The channel is clearly visible in Figure 21, and the water within the channel does not appear to move out of the channel or with great velocity. Also, the ebbing tide does not appear as strong in Figure 21 as in Figure 20. In comparing the movies generated from each simulation, the circulations predicted in simulation #1 seem more numerous and vigorous than those in simulation #2. The effects of the Lavaca River inflow are not readily apparent in comparing simulations #2 and #3.

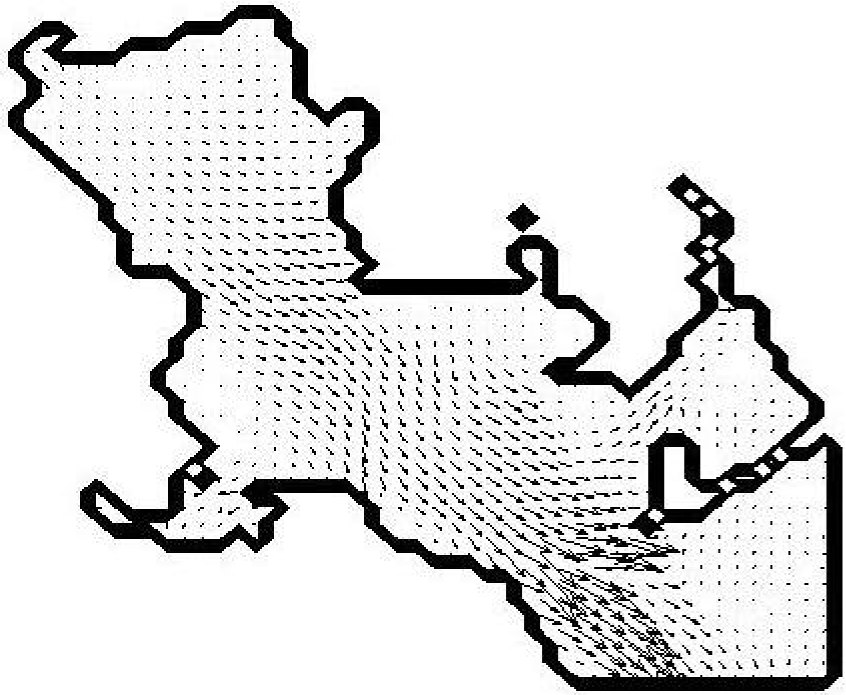


*Figure 20 – Vector Plot of Depth-Averaged Velocities for simulation #1(Without Channel or Inflow)*
*Note: Every second grid cell is included in the above plot.*

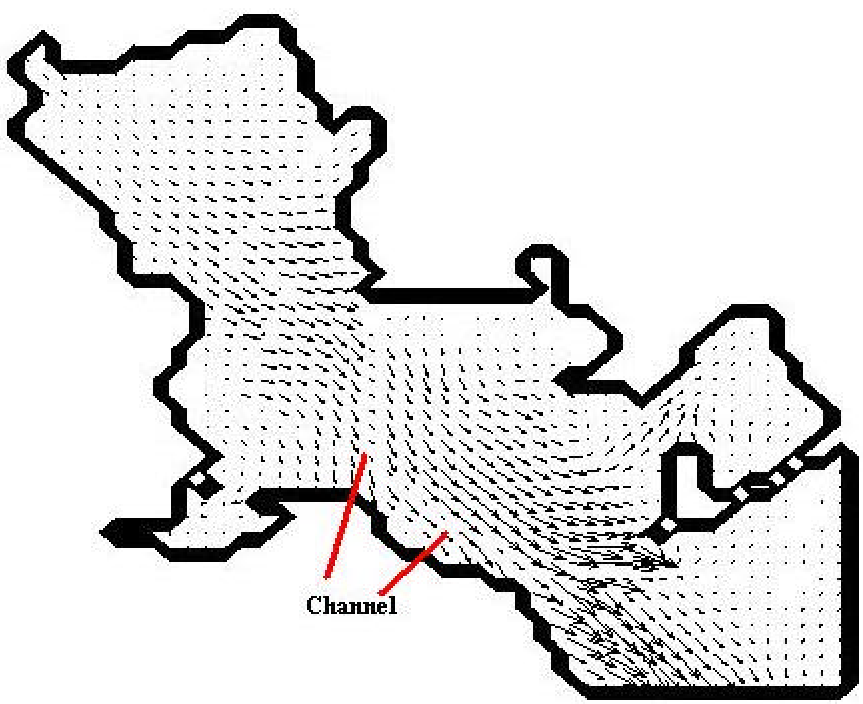



*Figure 21 - Vector Plot of Depth-Averaged Velocities for simulation #2 (With Channel and Without Inflow)*
*Note: Every second grid cell is included in the above plot.*

Similar results are visible when comparing the surface circulation patterns between the three simulations. As shown in Figures 22 and 23, the presence of the ship channel affects the circulation patterns throughout Lavaca Bay, with the most affects centered around the channel itself. However, in comparing the surface circulations with the channel but with and without inflow from the Lavaca River, the results are visibly identical (Figures 23 and 24).

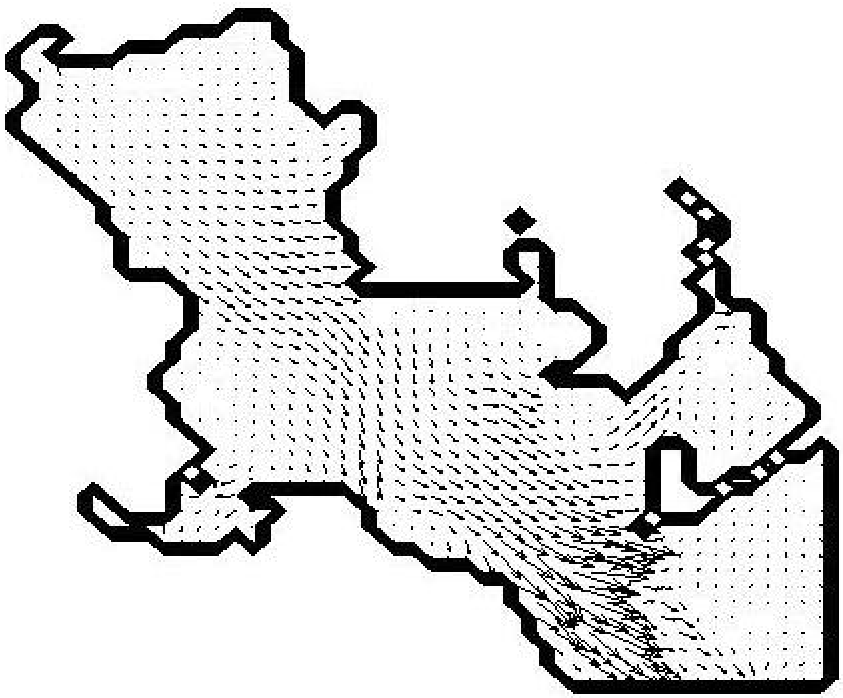


*Figure 22 - Vector Plot of Surface Velocities for simulation #1(Without Channel or Inflow)*
*Note: Every second grid cell is included in the above plot.*

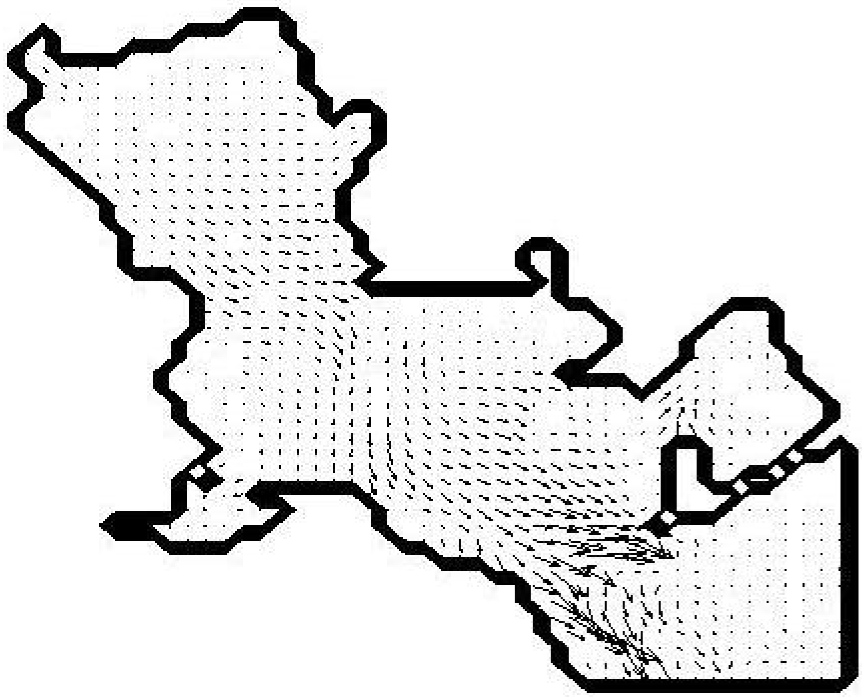


*Figure 23 - Vector Plot of Surface Velocities for simulation #2(With Channel and without Inflow)*
*Note: Every second grid cell is included in the above plot.*

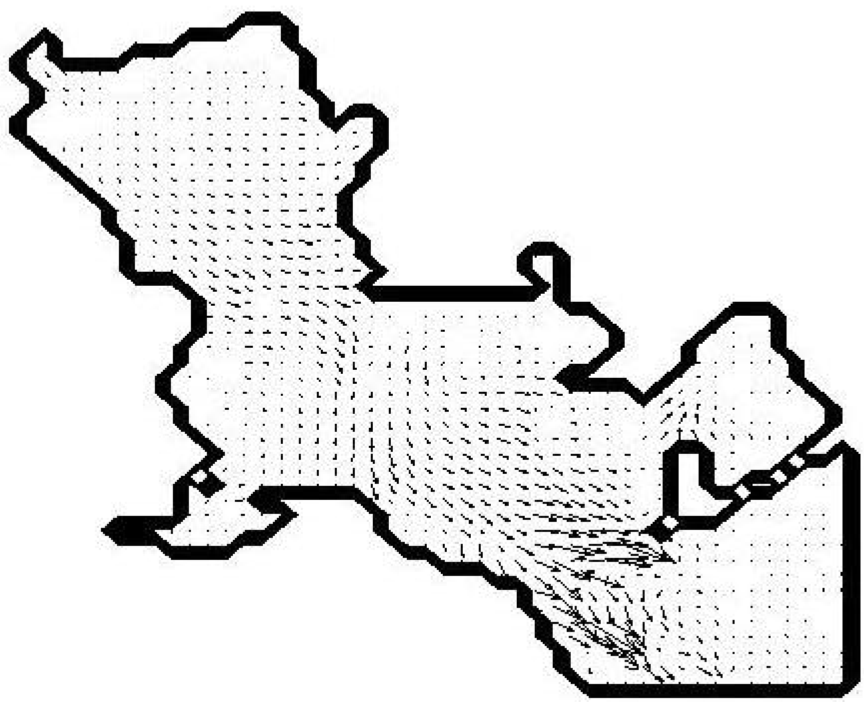


*Figure 24 - Vector Plot of Surface Velocities for simulation #3(With Channel and Inflow)*
*Note: Every second grid cell is included in the above plot.*

## Conversion of ELCOM Results to GIS Format

ELCOM results, as generated from each model run, are stored in the **NET**work **C**ommon **D**ata **F**orm **(NETCDF)** format. This format of data storage is machine independent, and it allows for an easy exchange of information between various users and programs. For this work and most other previous ELCOM applications, the netcdf files are processed and the results are visualized using the Matlab 6.1 software package. Dr. Ben Hodges, as well as researchers at the University of Western Australia, have written numerous Matlab scripts for processing and presenting the ELCOM results. In order to convert these results into a GIS format, some of these scripts were modified and combined. The conversion script, ***elcom_to_gis.m***, is available from Dr. Ben Hodges at CRWR.

The conversion script makes use of the gridded nature of the ELCOM results, where at any give time step a model output (ex. U_VELOCITY) is calculated for each grid cell in the X-Y model domain. The output is stored as a series of multi-dimensional arrays within the Matlab variable "data." The arrays are either 1, 2, or 3 dimensional. The one dimensional arrays store data related to the time of the simulation results. 2-dimensional arrays store data that does not change with time, such as bathymetry. The first dimension in such arrays corresponds to the cell number in the y-direction of the grid, and the second number pertains to the cell number in the grid's x-direction. A three dimensional array follows the same format as the 2-dimensional array except that the result time is stored in the first dimension. Therefore a 3-dimensional array stores gridded time series data.

```
data =

            x: [91x98 double]
            y: [91x98 double]
            z: [91x98 double]
     S_HEIGHT: [91x98 double]
        BATHY: [91x98 double]
   U_VELOCITY: [100x91x98 double]
   V_VELOCITY: [100x91x98 double]
   W_VELOCITY: [100x91x98 double]
       HEIGHT: [100x91x98 double]
         time: [100x1 double]
     set_type: 'SHEET_2D'
          day: [100x1 double]
         year: [100x1 double]
```

*Figure 25 – Sample ELCOM Data in Matlab – multiple arrays stored in the "data" variable.*

The multidimensional array format of the ELCOM data is very similar to the format of raster data used in GIS programs. As described previously, raster GIS data was used to create the ELCOM bathymetry files from which the results in this project are based. Specifically, the GIS bathymetry grid was exported into an ASCII text file, which was then transformed into the ELCOM bathymetry file using the ***bathymetry.exe*** program. Because the ELCOM grid cell locations and sizes are determined from the bathymetry, the ELCOM results have the identical spatial references as the raster GIS data from which the bathymetry is created. Therefore, in order to correctly display the ELCOM results in GIS, it is necessary to run the ***bathymetry.exe*** in reverse. The ***elcom_to_gis.m***

Matlab script performs this data conversion for a specified array in the "data" variable, and couples the ELCOM data with the necessary spatial reference information of the GIS grid. The final product is an ASCII text file containing the desired model results. This text file may then be imported into the GIS system and saved as a GIS grid.

```
data = get_db(cellstr('../ncfiles/s7_avg.nc'),...
             cellstr(char('U_VELOCITY','V_VELOCITY')),[14:14]);

velocity = sqrt(data.U_VELOCITY.^2 + data.V_VELOCITY.^2); % get the velocity magnitude
nfiles = size(velocity,1)                          % get the number of time slices
velocity(find(isnan(velocity))) = -9999

for ii = 1:nfiles                                  % create a file for each slice
    fid = fopen(['Velocity',num2str(ii),'.asc'],'w');   % open the file
    fprintf(fid, '%-12.9s', 'ncols  96');
    fprintf(fid, '\n');
    fprintf(fid, '%-12.9s', 'nrows  89');
    fprintf(fid, '\n');
    fprintf(fid, '%-12.17s', 'xllcorner  182515');
    fprintf(fid, '\n');
    fprintf(fid, '%-12.17s', 'yllcorner  7161459');
    fprintf(fid, '\n');
    fprintf(fid, '%-12.14s', 'cellsize  250');
    fprintf(fid, '\n');
    fprintf(fid, '%-12.20s', 'NODATA_value  -9999');
    fprintf(fid, '\n');
    adjust = size(velocity,2)-1  % Elcom addes cells around the original bathymetry
    adjust1 = size(velocity, 3)-1 % GIS system parameters don't account for these cells
    for jj = 2:adjust
        for kk = 2:adjust1
            count = fprintf(fid,'%-12.4f',velocity(ii,jj,kk)); % print a line
        end
        fprintf(fid,'\n'); % end of line
    end
    fclose(fid)
end
```

*Figure 26 – Sample elcom_to_gis.m script for 250m grid about Lavaca Bay*

In the above sample conversion script, the U_VELOCITY and Y_VELOCITY data are extracted from the s7_avg.nc file at the 14th time step. The ".nc" file extension signifies the file is in netcdf format, and the "s7_avg" file name signifies that this is the depth averaged data reported at each grid cell spanning the study area. The U_VELOCITY and V_VELOCITY data are the calculated velocities in the U and V (X and Y) directions. These values are multiplied in quadrature to create the *velocity* array, which is also 3-dimensional (There is only 1 time series result in the array, however). This velocity array stores the magnitude of the velocity of the water movement in each grid cell. A similar calculation is necessary to determine the angle of this movement. From a combination of the magnitude and angle data, velocity vector data may be generated. Creation of the velocity vector data is not shown in Figure 26.

The format conversion begins with the replacement of the Matlab generated "Not a Number" (NaN) values in the array with the NODATA value used in the GIS grids. The conversion is carried out with the combination of the *find* and *isnan* functions incorporated within Matlab. The NODATA value is always –9999 and is set as such when the original bathymetry grid is exported from GIS into ASCII format. After adjusting the NaN values, a “for” loop is initiated which creates a separate ASCII file for each time step included in the conversion. Each ASCII text file is created with the name “VelocityX.asc” where “X” is the number of the time step data to be represented in GIS format and “.asc” signifies that the file is in ASCII format. The following steps provide the spatial reference data that allows the GIS system to display the results in their proper location. The required fields are those fields found at the beginning of all exported GIS grid files, namely “ncols,” “nrows,” “xllcorner,” “yllcorner,” “cellsize,” and “NODATA_value.” The numbers following each one of these fields are specific to the location and grid size for which the program is used, and the values may be obtained from the exported bathymetry ASCII file (See Figure 18). The “fprintf” statements print the specified text to the VelocityX.asc file, and the “/n” code specifies the location of an end of line character. The next step is to write the individual velocity values into the ASCII file, with each value separated by spaces. This is carried out with two nested “for” loops, with the first loop controlling the rows of data and the second loop controlling the data columns. It is important to note that not all of the rows and columns from the velocity array are included in the ASCII file. Specifically, the first and last rows and columns are excluded.

In generating output, ELCOM adds NaN valued rows and columns along the border of the study area. These values do not affect the display of data in Matlab scripts, but do affect the display of the results in GIS. The added rows and columns are evident in comparing Figures 24 and 17, where the former shows 91x98 sized arrays and the later specifies an 89x96 grid. If these extra rows are not removed, the GIS system will include only part of the study area in the imported grid. Also, each grid cell will contain a value other than the value ELCOM calculated for the spatial area of the grid cell; the value will be the value of the cell with the row number and column number one higher than its own.

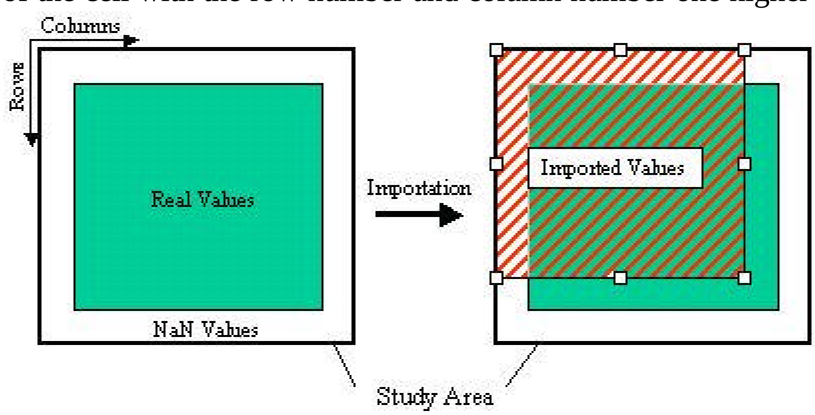



*Figure 27 – Location of Imported Values Relative to Real Values if extra NaN Values are not excluded*

When imported into a GIS system, an “uncorrected” ASCII file will display in a nonsensical manner. An “uncorrected” and “corrected” results display is shown in Figure 28.

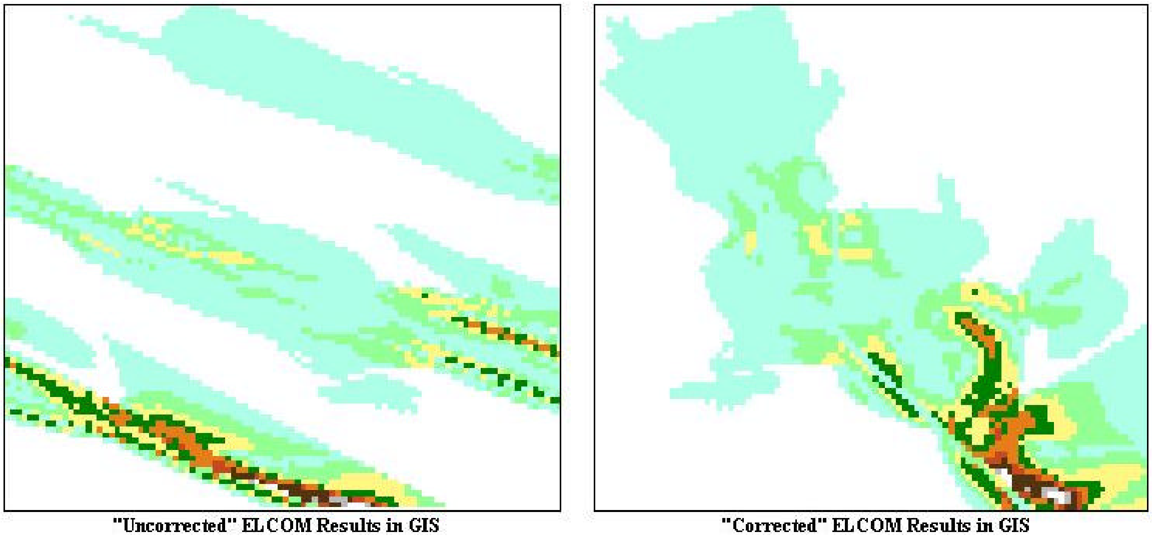



*Figure 28 – ELCOM Results in GIS (Velocity magnitudes with the channel and river inflow included)*

## Preliminary Modeling Conclusions

From the preliminary simulations that were completed, some significant conclusions can be reached. It is likely that the existence of the ship channel affects circulation patterns throughout Lavaca Bay. It is also evident that the existence of the ship channel necessitates the use of a 3-dimensional hydrodynamic model in order to predict the water circulation patterns within Lavaca Bay. As shown in the depth-averaged simulations including the channel (Figures 20 and 24), the calculated velocities within the channel are small and following the direction of the channel. Yet in the surface simulations, the flow seems relatively unrelated to the channel. It is likely that the water velocities calculated within the channel are so small and uni-directional that the depth-averaging process "dampens" the surface and upper layer calculated velocities. The resulting "dampened" depth averaged velocities do not accurately describe the water movement above the channel, and therefore a depth-averaged analysis is unsuitable for accurate modeling.

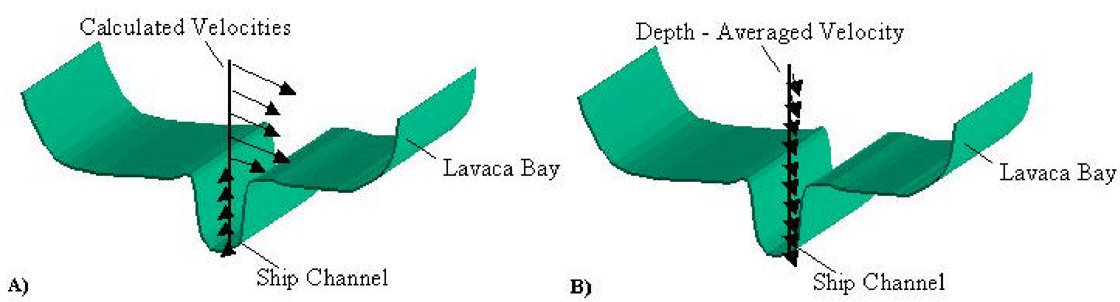



*Figure 29 – Effects of Depth Averaging while including the Ship Channel, A) Velocities calculated for the main part of the bay are of greater magnitude and different direction than those calculated in the ship channel, B) Depth Averaged velocities do not show the direction or magnitude of the velocities in A).*

Another possible hypothesis would be that the Bay circulation patterns are not strongly affected by inflows from the Lavaca River. This is suggested by the nearly identical results from simulations #2 and #3, where the only difference between the simulations is that simulation #2 does not include the river inflow. This hypothesis is not quite as strong, because the inflow data for the Lavaca River is real data measured in the Summer of 2001, during a period of traditionally low river flow. It is entirely possible that larger inflows would have a more significant effect on the circulation patterns within the Bay. Also, the river inflow is freshwater and is less dense than the more saline water in Lavaca Bay. The less dense freshwater is expected to form a plume in the upper layers of the water column, and this plume should be visible in the surface circulation simulations. However, such a plume is not visible in the simulations presented here because salinity differences were not included in the preliminary model setup. Salinity modeling is easily achievable with ELCOM, and it is to be included in future modeling efforts for Lavaca Bay.

The effects of the Lavaca River inflow may be more discernible in a model simulation without the ship channel. However, because the ship channel has been identified as a significant parameter in predicting water movement in Lavaca Bay, further simulations excluding the channel were not conducted. The effects of the inflows from other rivers draining to Lavaca Bay are potentially significant. However, flow values for these rivers, including Cox Creek and Huisache Creek, were not available from the USGS database (USGS, 2001). These streams were not included in the model presented here because they likely have negiglible flows compared to the flow of the Lavaca River. The existence of these rivers in DEM-based watershed delineations does not suggest that the rivers have significant flows. DEM-processing results only suggest where rivers would be located if any area has sufficient runoff or groundwater flows.

## Future Modeling Efforts

As intended, this preliminary modeling effort was effective at illuminating areas for further study. The ELCOM model can be used to temperature and salinity stratifications, storm events, the effects of wind shear, and evaporation effects. The model may also be used to predict hypoxia, and sediment transport (with some modifications). The next step in this work will be to refine the model input parameters, including the wind, tidal data, river inflows, salinity, and bay bathymetry. This last item has been shown to be significant, as reported in this work.

Of the possible bathymetry alterations, the most obvious is to determine the effects of differing cell sizes on the predicted circulation patterns. The 250m-cell bathymetry grid was used for this preliminary study because it was sufficiently small in that it allowed for more simulations in a shorter time. Another important aspect of bathymetry that needs to be investigated involves the quality of the bathymetry source data and the grid interpolation. The source data (GEODAS data) used in this work did not suggest the existence of a ship channel, and as shown it is likely that the ship channel influences bay circulation. Therefore the quality of the bathymetry data needs to be assessed and improved. Also, the ship channel location needs to be accurate and verifiable. The channel location, as used in this modeling effort, was determined based on visual comparisons with published maps. In order to develop an accurate model of the Bay system, the actual location of the channel must be known. One possible solution to this accuracy problem is the use of digital navigation charts, which are available for purchase from various agencies and companies.

A second issue related to bathymetry accuracy stems from the method of grid interpolation from the bathymetry sounding points. Numerous interpolation schemes exist, and not all schemes and scheme parameters are appropriate for a given study area. A simple comparison of different interpolation schemes may suggest that the IDW method used in this work is not the appropriate technique for use in describing Lavaca Bay bathymetry. Potentially more important than the interpolation scheme is the inclusion of interpolation barriers. As shown in Figure 11, the interpolations for this work were carried out without barriers. This caused the exclusion of the various spoil and dredge islands that exist within Lavaca Bay. These islands will certainly alter the circulation patterns in the bay, and they are crucial in the study of mercury transport in bay sediment. One current hypothesis regarding the mercury contamination within the bay is that the mercury is derived from sediment deposited on one or more of the islands. It is therefore impossible to test this hypothesis without including the islands in the simulation.

Work has begun on interpolating bay bathymetry with the islands and the bay shoreline included as interpolation barriers. The *barriers.shp* theme was created for this purpose, and it is included on the Task E data CD-ROM. Unfortunately, interpolation with barriers is an extremely computationally intensive process, and this interpolation was not completed in time for inclusion in this report. An additional benefit to the use of interpolation barriers is that the bathymetry at the barrier is automatically set to 0, or mean sea level (in the case of bathymetry interpolation). With the interpolation scheme and grid clipping technique used in this work, the water depth along the bay shore may not be equal to or near zero (mean sea level).

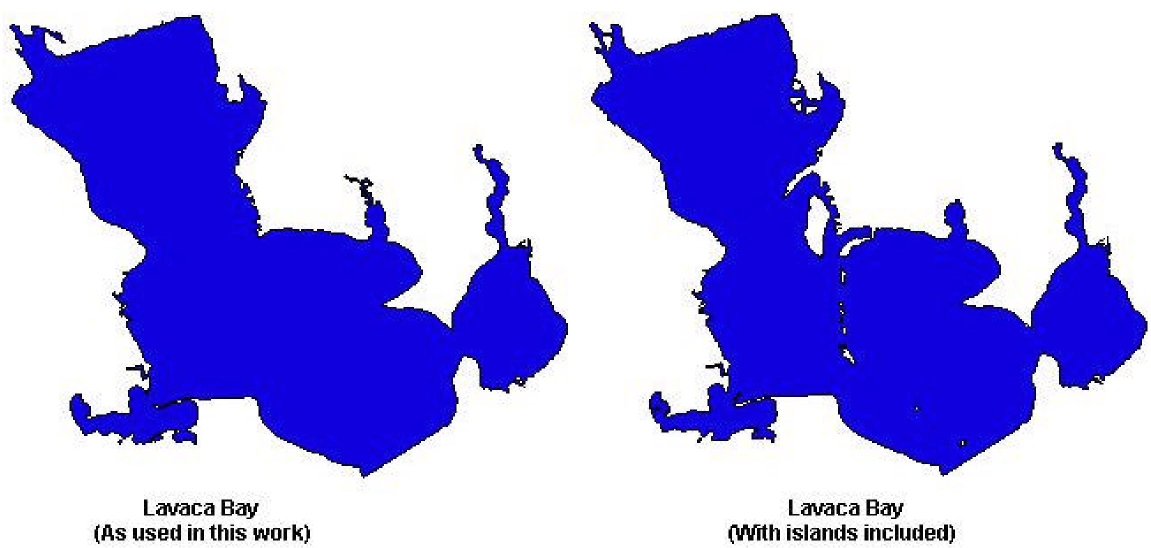



*Figure 30 – Lavaca Bay Spatial Extent – with and without islands*

A second area of important future study involves assessing the accuracy of the exchange processes between Lavaca Bay and Matagorda Bay. Each of the model simulations predicted that most of the faster and rapidly changing flows occurred at or near the interface between the two waterbodies (Figures 17-21). This exchange will therefore greatly influence the distribution of contaminants and sediment throughout both bays, and will likely control the flushing time of substances from Lavaca Bay. This exchange is likely to be tidally driven, and therefore an accurate model requires accurate tidal data. The tide data used in this work was real tide measurements made at Port O'Connor, which is located near the outlet of Matagorda Bay and outside of our study area. Tide data is also available for Port Lavaca, which is within the study area. Clearly both datasets should be incorporated into the model, assuming that the actual tide at the open boundary cells in the model study area is an intermediate value between the two known tidal heights. A second possibility would involve modeling Matagorda Bay in its entirety and using the Port O'Connor tide data at the interface between Matagorda Bay and the Gulf of Mexico.

The existence of the ship channel will also likely affect the exchange processes between Lavaca Bay and Matagorda Bay. The channel, due to its limited extent and linear features, may act as a conduit for transporting water and contaminants. Testing this hypothesis will involve detailed calculations of water movement within the ship channel, with the end result being a comparison of the flux from the channel and from the overall waterbody. In order to calculate the movement of water through the ship channel, the location, width, and depth of the ship channel must be known with greater accuracy than presented in this preliminary project.

A third factor affecting the exchange of material between Lavaca Bay and Matagorda Bay is likely to be the density differences between the saline water from the Gulf of Mexico and the fresh water from the Lavaca River. These waters of differing salinities may cause local density stratifications as water is exchanged between the two bays, therefore reducing the vertical movement of water and nutrients in the water column. Areas of such stratification have been shown to be hypoxic in Corpus Christi Bay (Ritter and Montagna, 1999). This stratification is most probable in the summer months when the freshwater inflow from the Lavaca River is relatively low. Models should be run in order to predict where density stratification might occur, and therefore where hypoxic conditions might be expected. This information would be essential in the TMDL determination process for dissolved oxygen, for it would help direct the field sampling excursions.

Stratification is easily calculated and visualized with ELCOM and Matlab. The ELCOM model, because it is a fully 3-dimensional hydrodynamics model, is able to produce cross-section data as well as plan view data displayed in this report. The cross-sections may be defined by the user, and can be tailored to areas of the bay that are considered important. Also, it is easy to verify model results with field data when the results are presented in cross-section format.

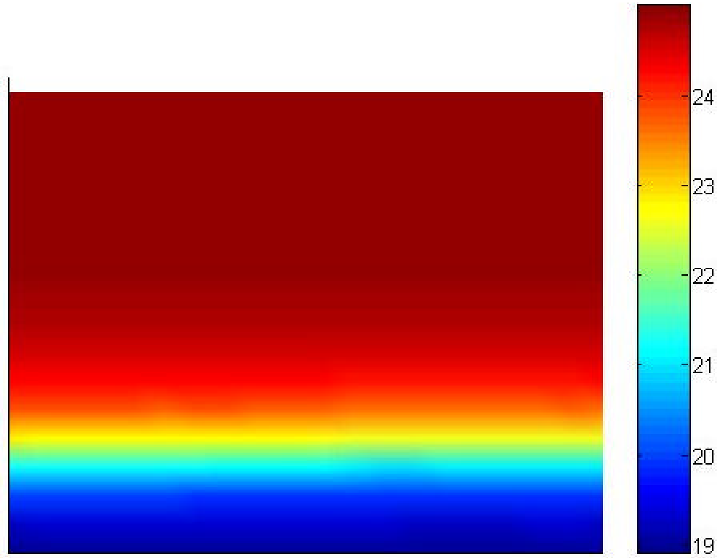



*Figure 31 – Sample Results in Cross Section – Temperature variations with depth in a "Square Box" lake under wind stress (Units are degrees centigrade)*

## References


?? Davis, Kimberly, and Maidment, David. *Object-Oriented Modeling of Rivers and Watersheds in Geographic Information Systems*. CRWR Online Report #00-7 *http://www.crwr.utexas.edu/reports/2000/rpt00-7.shtml*

?? *Fish-n-Go. Co.* map of Matagorda Bay. Provided by Dr. Paul Montagna of the University of Texas Marine Science Institute, Port Aransas, TX.

?? Furnans, Jordan, and Olivera, Francisco. 2001. "Drainage Systems." Chapter 4 of *ArcGIS Hydro Data Model*. ESRI press. Set to print 10/01.

?? Hodges, Ben R., Imberger, Jorg, Saggio, Angello and Winters, Kraig B. 2000. "Modeling basin-scale internal waves in a stratified lake". *Limnological Oceanography* 45(7):1603-1620.

?? NetCDF Data Format Descriptions, available at: http://www.unidata.ucar.edu/packages/netcdf/ (as of 9/3/01)

?? NOAA Bathymetry Data – the GEODAS System, available at: http://www.ngdc.noaa.gov/mgg/geodas/geodas.html (as of 9/3/01)

?? Ritter, C. and Montagna, Paul A. 1999. "Seasonal Hypoxia and models of benthic response in a Texas Bay." *Estuaries*. 22:7-20.

?? Samuels, Victoria 2001. *An Algorithm to Delineate Coastal Watersheds for TMDL Development*. CRWR Online Report #01-3 *http://www.crwr.utexas.edu/reports/2001/rpt01-3.shtml*

?? *USGS, 1996.* 1-Degree USGS Digital Elevation Models. *Internet Site: http://edc.usgs.gov/glis/hyper/guide/1_dgr_dem*

?? *USGS, 1999.* National Elevation Dataset Product Methodology. *Internet Site: http://edcnts12.cr.usgs.gov/ned/Methodology.htm*

?? *USGS, 2001*. Daily Stream flow values for Lavaca Bay Area. *Internet Site: http://tx.water.usgs.gov/cgi-bin/current/?basin=lavaca&type=unit*

?? 1-Ward, George H. Jr., and Benaman, Jennifer. *A Survey and Review of Modeling for TMDL Application in Texas Watercourses*. December 1999. *http://www.crwr.utexas.edu/online.shtml*

?? 2-Ward, George H. Jr., and Benaman, Jennifer. *Models for TMDL Application in Texas Watercourses: SCREENING AND MODEL REVIEW*. December 1999. *http://www.crwr.utexas.edu/online.shtml*

Appendix A

## Data CD-ROM Contents Description and Layout

The data on this accompanying CD is distributed in two folders. Each folder contains the following data and information:

Geospatial: *Geospatial* file; Regional *Data* folder (with many subfolders); *Tables* folder; *Metadata* folder

Modeling: *Modeling* file; *Data* Folder - containing multiple subfolders; *Results* folder

The contents of each of these folders is given below:

*Geospatial*

The following layers are in the Lavaca Bay geo database. The layers contain geospatial information pertaining to the Lavaca Bay - Matagorda Bay drainage areas, which were determined through watershed delineation based on a 30m Digital Elevation Model. The object of the delineation was to determine the land areas that contribute flow into Lavaca Bay only. Portions of Matagorda Bay were included in the delineation in order to account for the possible hydrodynamic exchange (and contaminant exchange) between Lavaca Bay and Matagorda Bay. The resultant watersheds (*wtrshd1*, *wtrshd2*) were buffered to a distance of 500m and were altered so that they include the bay systems along the Gulf Coast. This complete area was used to clip the other data layers. The "File Name" is the name of the data file containing each layer. Each folder contains a different data layer for the entire region of study. Hyperlinks from the "Data" descriptions are used to refer to each layer's metadata. The metadata for layers can also be found in the “Metadata” folder. The original source of the data is also linked by a hyperlink.

| File Name | Data | Source |
|---|---|---|
| wtrshd1 | Delineated Watershed Boundaries - Reach Scale | CRWR |
| wtrshd2 | Delineated Watershed Boundaries - Bay Scale | CRWR |
| filldem | 30 m Digital Elevation Model, Burned & Filled | CRWR |
| fdr | 30 m Flow Direction Grid | CRWR |
| fac | 30 m Flow Accumulation Grid | CRWR |
| segsl99 | Surface Water Quality Segment Hydrography | TNRCC |
| segsl99poly | Surface Water Quality Segment Polygons | TNRCC |
| hydro_poly_g | 1:24,000 Scale Hydrography - General Polygons | TGLO |
| hydro_poly_d | 1:24,000 Scale Hydrography - Detailed Polygons | TGLO |
| hydro_arc_g | 1:24,000 Scale Hydrography - General Arcs | TGLO |
| hydro_arc_d | 1:24,000 Scale Hydrography - Detailed Arcs | TGLO |
| statsgo | STATSGO soil coverage | NRCS |
| ssurgo | SSURGO soil coverage | NRCS |

Appendix A

| | | |
|---|---|---|
| nhd | NHD digital stream network | USGS |
| nhdpoly | NHD Waterbodies | USGS |
| landuse | National Land Cover Data | EPA |
| pcs | Municipal Dischargers | EPA-BASINS |
| Idischarge | Industrial Dischargers | EPA-BASINS |
| nwsgage | NWS Weather Stations | EPA-BASINS |
| nwsarea | NWS Areas of Coverage | EPA-BASINS |
| gages | USGS Flow Gage Locations | USGS |
| dams | Dam Locations | EPA-BASINS |
| counties | County Boundaries | EPA-BASINS |
| citylimits | City Boundaries | TGLO |
| UrbanAreas | Urban Area Boundaries | TGLO |
| roads | USDOT Roadways | TGLO |
| hwys | Major Highways | TGLO |
| huc | Hydrologic Cataloging Unit Boundaries | EPA-BASINS |
| wdm | Watershed Data Management Stations | EPA-BASINS |
| pws | Public Drinking Water Supply Locations | TNRCC |
| wq_stat | Surface Water Quality Monitoring Stations | EPA-BASINS |
| wqobs | Water Quality Observation Stations | EPA-BASINS |
| nsi | National Sediment Inventory Stations | EPA-BASINS |
| superfund | Superfund (National Priority List) Sites | TNRCC |
| tri | Toxic Release Inventory sites | EPA-BASINS |
| federal | Federal Congressional Districts | TLC |
| shd | State House Districts | TLC |
| ssd | State Senate Districts | TLC |
| ncdc | National Climatic Data Center (NCDC) Precipitation Gage Locations | NCDC |

| | | |
|---|---|---|
| landfill | Solid Waste Landfill Locations | TNRCC |
| cog | Council of Government Regions | TNRCC |
| watright | Surface Water Rights Diversion Points | TNRCC |
| eco_region | Ecoregions | EPA-BASINS |
| service | TNRCC Service Regions | TNRCC |
| classb | TNRCC Class B Land Application Sites | TNRCC |
| pihw | Permitted Industrial & Hazardous Waste Sites | TNRCC |
| aquifers | Major Aquifer | TWDB |
| veg | Vegetation layer | TGLO |
| airmon | Air Quality Monitoring Stations | TNRCC |
| airports | Airport Landing Strips (TIGER) | TNRCC |
| landpts | Landmark Points (TIGER) | TNRCC |
| landareas | Landmark Areas (TIGER) | TNRCC |
| nonvis | Nonvisible Boundaries (TIGER) | TNRCC |
| placnams | Geographic Names (TIGER) | TNRCC |
| roads_tiger | Roads (TIGER) | TNRCC |
| railways_tiger | Railways (TIGER) | TNRCC |
| streams | Streams & Shorelines (TIGER) | TNRCC |
| xmission | Transmission, Power & Pipe Lines (TIGER) | TNRCC |

*Geospatial Data Layers Notes*

- The SSURGO data layer is missing data for several counties.  Michael L. Golden (Michael.Golden@tx.usda.gov) of the Natural Resources Conservation Service Texas State Office in Temple stated that these counties are still being compiled.

Appendix A

*Data Tables*

The following tables are in the database. The "file name" is the name of the data file in the "tables" folder.

| Table Name | Data | Source |
|---|---|---|
| layer.dbf | STATSGO Soil Layer Data | NRCS |
| comp.dbf | STATSGO Soil Component Data | NRCS |
| mapunit.dbf | STATSGO Soil Map Unit Data | NRCS |
| nsi_bio.xls | NSI Biotoxicity Data | EPA-BASINS |
| nsi_tis.xls | NSI Tissue Residue Data | EPA-BASINS |
| nsi_wsh.xls | NSI Watershed | EPA-BASINS |
| nsi_sed.xls | NSI Sediment Chemistry Data | EPA-BASINS |
| nsi_ref.dbf | NSI Reference Table | EPA-BASINS |
| ncdc_precip.xls | NCDC Monthly Precipitation Data | NCDC, CRWR |
| tx.wdm | Watershed Data Management Meteorological data for Texas | EPA-BASINS |

*Data Tables Notes*

- tx.wdm can only be viewed in BASINS, or the support software WDMUtil, available from the BASINS website or accompanying BASINS 3.0.

*Acronyms*

| Acronym | Agency Name |
|---|---|
| CRWR | Center for Research in Water Resources (University of Texas at Austin) |
| EPA | United States Environmental Protection Agency |
| EPA-BASINS | U.S. EPA Better Assessment Science Integrating Point and Nonpoint Sources |
| NCDC | National Climatic Data Center |
| NRCS | Natural Resources Conservation Service |
| TGLO | Texas General Land Office |
| TLC | Texas Legislative Council |
| TNRCC | Texas Natural Resource Conservation Commission |
| TNRIS | Texas Natural Resources Information System |
| TWDB | Texas Water Development Board |
| USGS | United States Geological Survey |

Appendix A

## *Modeling*

### *Hydrodynamics - Data Support*

The following layers are in the Lavaca Bay Hydrodynamic Modeling database. The layers contain geospatial information pertaining to Lavaca Bay and its hydrologic characteristics. This information is suited for use in various 2D or 3D hydrodynamics models that strive to predict water circulation patterns in the Bay. For this study, a preliminary hydrodynamic model of Lavaca Bay was constructed with the ***E***stuaries and ***L***akes ***CO***mputer ***M***odel (**ELCOM**), created by Dr. Ben Hodges and distributed by the Centre for Water Research (CWR) at the University of Western Australia. ELCOM is a 3D hydrodynamics model that involves Coriolis forcing and various turbulence modeling methods in solving hydrostatic, Bousinesq, and time-dependent Reynolds Averaged Navier-Stokes (RANS) equations for fluid flow. The model had been recently applied to predicting internal wave propagation in Lake Kinneret in Israel, as well as other studies in Australia, Greece, Germany, and Japan. Along with this project, US applications of the model include attempts to describe the estuarine dynamics of the Jamaica Bay in New York, as well as the flow patterns in Lake Travis in Central Texas. The data layers provided here were used in ELCOM runs that were designed to demonstrate the model's potential for determining bay circulations. The modeling is preliminary only, and the results have not been verified with field data. One outcome from this project was a method for displaying the ELCOM results as raster grids in ArcGIS or ArcView.

The "File Name" is the name of the data file containing each layer. The files are divided into sections, with the files located in a folder with the section name (i.e. "Spatial," "Baythmetry," or "Environmental"). Hyperlinks from the file "Descriptions" are used to refer to each layer's metadata. The metadata for layers can also be found in the "Metadata" folder. The original source of the data is also linked by a hyperlink.

| Spatial Orientation Files (GIS Format) | | |
|---|---|---|
| File Name | Description | Source |
| waterbodies.shp | Study Area Coastal Waterbodies | NHD, CRWR |
| lavaca.shp | Lavaca Bay Extent, excluding Islands | NHD, CRWR |
| toburn.shp | Hydrography for DEM Burning | NHD, TGLO, CRWR |
| segments.shp | Lavaca Bay Shoreline Segments | NHD, CRWR |
| drainage.shp | Hydrography for Watershed Delineation | NHD, TGLO, CRWR |
| withislands.shp | Lavaca Bay Extent, including Islands | NHD |
| barriers.shp | Island and Bay Boundaries | NHD, CRWR |
| ship_channel.shp | Estimated Ship Channel Location | CRWR |
| **Bay Bathymetry Digital Elevation Models (GIS Format)** | | |
| bath_points.shp | Historical Sounding Points - Bathymetry | GEODAS |
| bath50m | 50m Bathymetry Grid | CRWR |
| bath100m | 100m Bathymetry Grid | CRWR |
| bath150m | 150m Bathymetry Grid | CRWR |
| bath200m | 200m Bathymetry Grid | CRWR |
| bath250m | 250m Bathymetry Grid | CRWR |
| channel250m | 250 Ship Channel Grid | CRWR |
| channel150m | 250 Ship Channel Grid | CRWR |
| channel100m | 250 Ship Channel Grid | CRWR |
| 250m_channel | 250m Bathymetry for ELCOM | CRWR |
| 150m_channel | 150m Bathymetry for ELCOM | CRWR |
| 100m_channel | 100m Bathymetry for ELCOM | CRWR |

| Environmental Forcing Data (Non-GIS Format) | | |
|---|---|---|
| PORTOCONNOR_tides.txt | Tidal Height -Port O'Connor | CBI |
| LAVACA_tides.txt | Tidal Height - Port Lavaca | CBI |
| Watertemp.txt | Water Temperature at Port O'Connor | CBI |
| Windspeed.txt | Wind Speed at Port O'Connor | CBI |
| winddir.txt | Wind Direction at Port O'Connor | CBI |
| pressure.txt | Barometric Pressure at Port O'Connor | CBI |
| Inflow.xls | Estimated Inflow - Lavaca River | LNRA, CRWR |
| Salinity_and_Temperature.txt | Salinity, Temperature, DO Measurements | UTMSI |
| Evap.htm | Monthly Historical Evaporation Data | TWDB |
| Precip.htm | Monthly Historical Precipitation Data | TWDB |

*Preliminary ELCOM Model Results*

The following QuickTime movies demonstrate predicted water circulation patterns in Lavaca Bay under varying conditions. These movies are examples of the types of output available from the **ELCOM** model. The results shown are plan view representations of Lavaca Bay, however the model results may also be displayed in cross-section, along the ship channel, or along surfaces of equal value. Only the plan view results are shown here, because only these results are viewable as grids ArcView or ArcGIS. The modeling process and the display of results in GIS format is described fully in the *Task E* report.

The "file name" is the name of the movie file in the "Results" folder, and the movie may be accessed by clicking on the name. The "Data" column contains descriptions of the model inputs for which the movie was generated.

*** Movies are viewable with the QuickTime Movie Player. This movie player is freely available from http://www.apple.com/quicktime/.

| File Name | Data | Source |
|---|---|---|
| surface_circulation1.mov Partial Results movie | Surface Water Circulation - 250m Bathymetry only | CRWR |
| surface_circulation2.mov Partial Results movie | Surface Water Circulation - 250m Bathymetry only with Inflow | CRWR |
| surface_circulation3.mov Partial Results movie | Surface Water Circulation - 250m Bathymetry only with Inflow and Channel | CRWR |
| average_circulation1.mov Partial Results movie | Depth-Averaged Water Circulation - 250m Bathymetry only | CRWR |
| average_circulation2.mov Partial Results movie | Depth-Averaged Water Circulation - 250m Bathymetry with Inflow | CRWR |
| average_circulation3.mov Partial Results movie | Depth-Averaged Water Circulation - 250m Bathymetry with Inflow and Channel | CRWR |

*Acronyms*

| Acronym | Agency Name |
|---|---|
| CBI | Conrad Blucher Institute |
| CRWR | Center for Research in Water Resources (University of Texas at Austin) |
| GEODAS | National Geophysical Data Center - NOAA |
| LNRA | Lavaca-Navidad River Authority |
| NHD | National Hydrography Dataset - United States Geological Survey |
| TGLO | Texas General Land Office |
| TWDB | Texas Water Development Board |
| UTMSI | University of Texas Marine Science Institute |

Appendix A

*Projection*

All of the GIS data provided one this CD are in the TCMS Albers projection. The parameters are:

Projection ALBERS
Datum NAD83
Zunits NO
Units METERS
Spheroid GRS1980
Xshift 0.0000000000
Yshift 0.0000000000
Parameters
27 30 0.000 /* 1st standard parallel
35 0 0.000 /* 2nd standard parallel
-100 0 0.000 /* central meridian
18 0 0.000 /* latitude of projection's origin
1500000.00000 /* false easting (meters)
6000000.00000 /* false northing (meters)

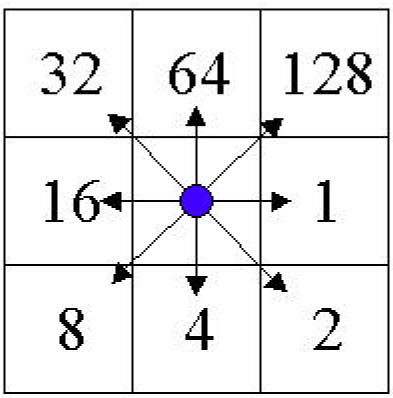
# Appendix B

** The following text and pictures is taken directly from Furnans and Olivera (2001)

## Use of Digital Elevation Model Data in Drainage Delineation

The standard method for delineating drainage areas involves the use of a digital elevation model, or DEM. DEMs are digital records of terrain elevations for ground positions at regularly spaced horizontal intervals. These grids are derived from standard topographic quadrangle maps through the use of hypsographic data and /or photogrammetric methods[5]. Such grids are easily processed with the ArcGIS hydrology tools in the Spatial Analyst extension. The following discussion describes the basic theory behind the watershed delineation functions in ArcGIS.

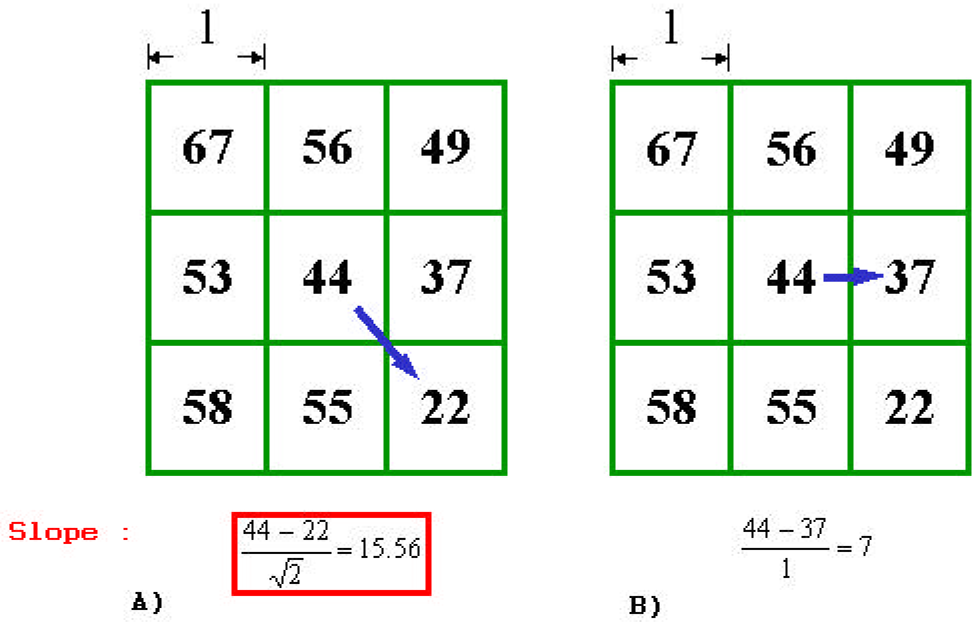
The grid operations involved in watershed delineation are all derived from the basic premise that water flows downhill, and in so doing it will follow the path with the largest gradient (steepest slope). In a DEM grid structure, there exist at most 8 cells adjacent to each individual grid cell. (Cells on the grid boundary are not bounded on all sides) Accordingly, water in one cell travels in 1 out of at most 8 different directions in order to enter the next downstream cell. This concept is referred to as the 8-direction pour point model.




*8-Direction Pour Point Model for Grid Operations*

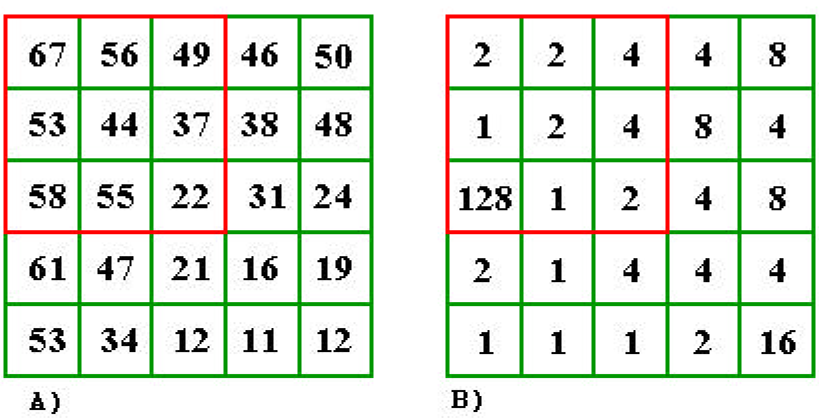
In this grid representation, water in a grid cell may flow only along one of the eight paths depicted by arrows. The number in each cell represents the direction water travels to enter the nearest downstream cell, and the numbering scheme has been set by convention. The numbers were determined from the series $2^x \; x \in \{0,1,\ldots,7\}$.

Watershed delineation with the 8-direction pour point model is best explained with an illustration. For demonstration purposes, assume a section of a sample DEM grid is given. The numbers in each grid cell represent the cell elevation.

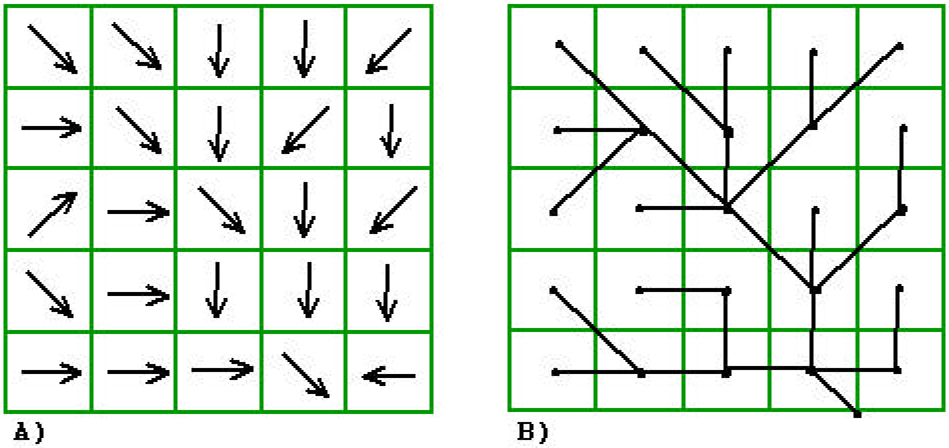



*Slope Calculations with the 8-direction Pour Point Model – A) Slope calculated for diagonal cells; B) Slope calculated for cells with common sides.*

Focusing on the center cell (value = 44), only 2 of the 8 adjacent cells contain values less than 44. This limits the possible flow directions in that water will not flow to a cell with a greater elevation. The water will flow in the direction in which the greatest elevation decrease per unit distance is obtained. In **A)**, this slope is calculated along the diagonal by subtracting the destination cell value from the original cell value, and dividing by $\sqrt{2}$, the distance between the cell centers assuming each cell is 1 unit long on each side. In **B)**, the slope is calculated to the non-diagonal cell. It is equal to the elevation difference because the distance between the cell centers is unity. In this case, the diagonal slope is greater, and water will flow toward the bottom right cell. The center cell is then assigned a flow direction value of 2. This process is then repeated for each of the cells in the DEM grid, and a new grid is created to store the results of the calculations. This new grid, called the Flow Direction grid, contains cells with only the numerical values dictated by the 8-direction pour point model

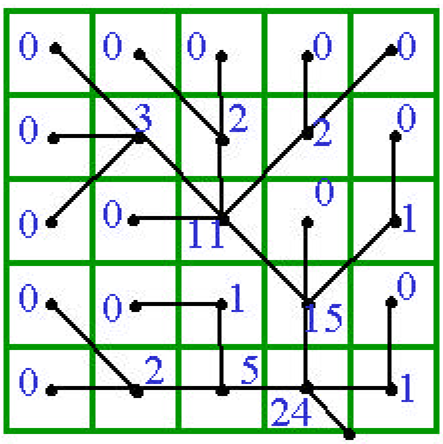



*Grid Operations – A) DEM Grid; B) Flow Direction Grid. Note: Area in red is from the previous figure*




*Physical Representation a Flow Direction Grid – A) with directional arrows; B) As a flow network*

It is from the flow direction grid that the flow accumulation grid is calculated. This grid records the number of cells that drain to an individual cell in the grid. Note that the individual cell itself is not counted in this process.

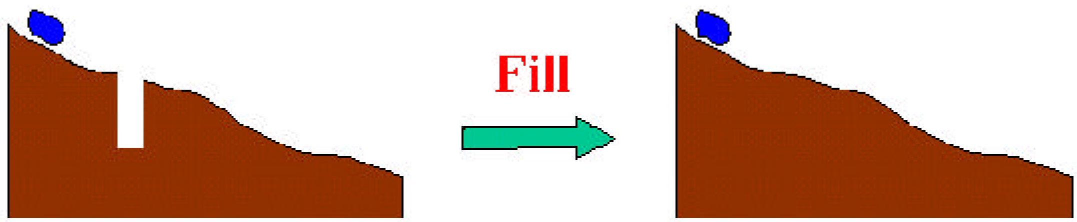



| | | | | |
|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 |
| 0 | 3 | 2 | 2 | 0 |
| 0 | 0 | 11 | 0 | 1 |
| 0 | 0 | 1 | 15 | 0 |
| 0 | 2 | 5 | 24 | 1 |

*Flow Accumulation – number of cells draining to a given cell (blue) along the flow network*

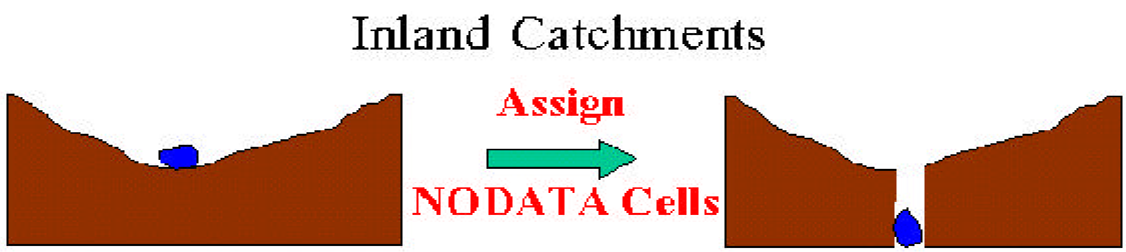
At this point, it is necessary to consider the possibility that flow might accumulate in a cell in the interior of the grid, and that the resulting flow network may not necessarily extend to the edge of the grid. An example of such a situation is the Great Salt Lake in Utah, which is an interior sink. None of the precipitation that falls on the Great Salt Lake watershed travels through a river network to the ocean. This situation poses a problem for automated delineation, for the flow that "accumulates" in an inland sink does not reach an outlet from which the delineation process may take place. A second potential problem arises, however, if the DEM grid itself contains artificial lows in the terrain, due to errors in elevation determination or grid development. These artificial sinks must be eliminated in order to accurately delineate watersheds.

Any artificial sinks or inland catchments in the DEM are removed through the use off the *Fill* function in ArcGIS. This function alters the elevations of the offending cells through the use of an interpolation function, as shown below.




*Filling an artificial pit in the DEM*

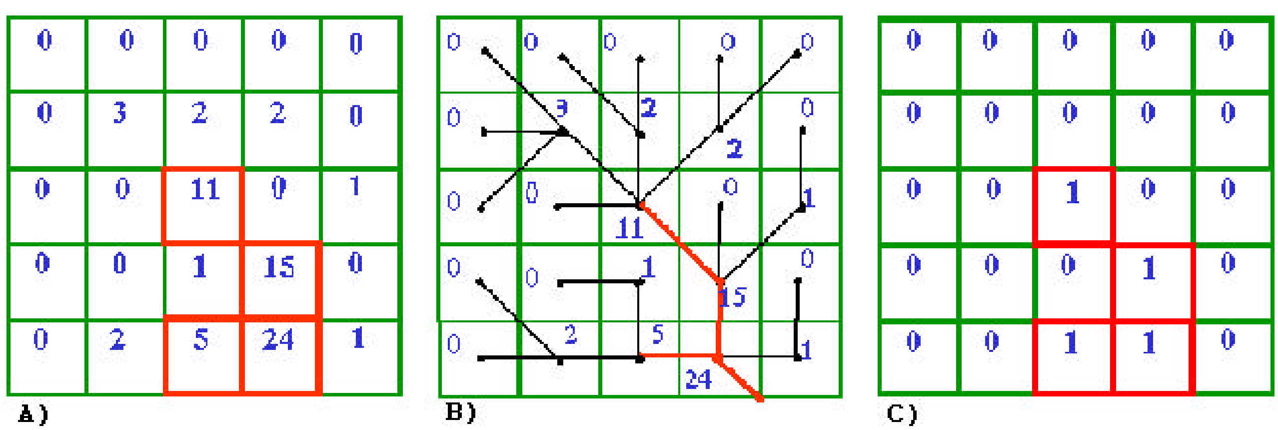
To allow for the existence of known inland catchments in the DEM, special processing is needed before running the Fill function. One such process is to assign a NODATA value to the lowest elevation cell in the inland catchment; such a cell would be treated as an outlet in that it would allow water to "flow out" of the system. In the network model, this is a Hydro Edge that ends in a sink.




*DEM alteration to allow delineation of inland catchments*

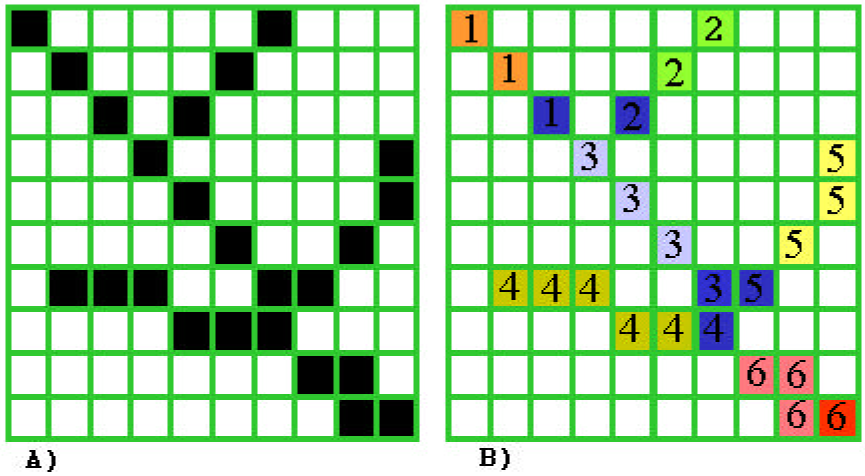
The Fill function should be run before the flow direction grid is created because artificial pits can significantly alter the flow direction. Similarly, if inland catchments are present, a program should be run to handle them before the Fill function is run or the flow direction grid is created.

With a flow accumulation grid, streams may be defined through the use of a threshold flow accumulation value. For example, if a value of 5 were set as the threshold, than any cell with flow accumulation greater than 5 would be considered a stream. Cells with flow accumulations greater than or equal to the threshold are given a value of 1 in a newly created *Stream Grid*, with all other cells containing the value 0.




*Stream Definition from the Flow Accumulation Grid and a threshold value – A) Grid cells with accumulation greater than or equal to 5 are considered stream cells (red); B) Streams identified on the flow network (red); C) Stream Grid*

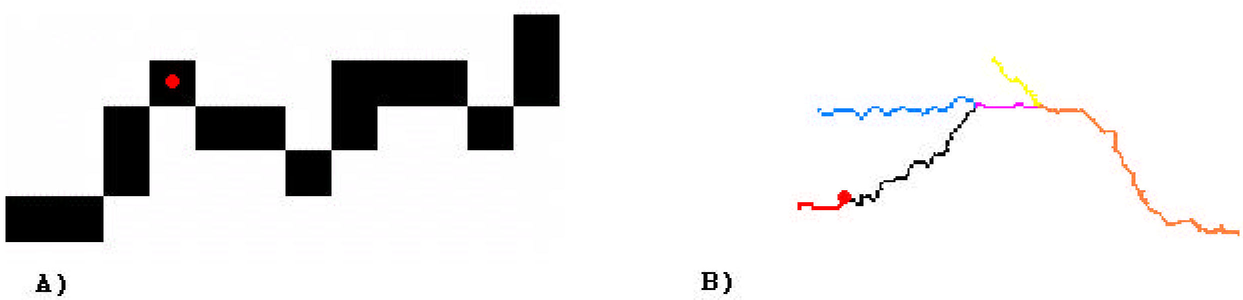
The next step is to divide the stream network into distinct stream segments – this is useful if the purpose of the delineation is to determine the individual Catchments. If only the overall watershed is desired, the delineation function could be used on the established grids as long as the outlet cell is defined. For this discussion, Catchments are delineated.




*Stream Links defined – A) Stream Grid representation, B) Stream Links (numbers) defined, link outlets (blue), watershed outlet (red)*

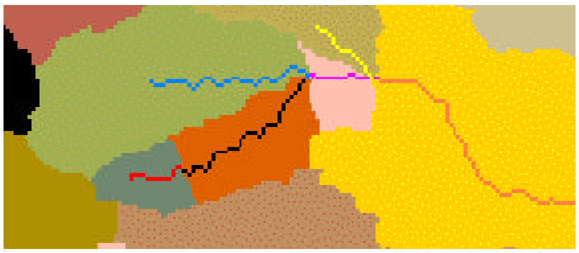
To segment the stream network, the *Streamlink* function in ArcGIS is used on the Stream Grid, as in the figure above. This function determines stream links within the network, and assigns each link a unique number, or GridCode. These links are drainage paths in the ArcGIS Hydro data model. Each cell within a link is assigned the same number. The most downstream cell in each link is the link outlet cell, which is represented as a drainage point in the data model. An outlet grid, with the individual outlets cells (in **B,** the blue or red cells) containing GridCodes and all other cells containing NODATA, is then produced from the streamlink grid. GridCodes can be used as DrainIDs when the resulting data is loaded into the data model.

At this point additional outlets may be added to the outlet grid, and the Stream Link Grid is then adjusted to add the newly created links. Such extra outlets, represented as *HydroPoints* in the ArcGIS Hydro Data Model, may represent water supply locations, monitoring stations, etc.




*Adding outlets on a stream grid – A) an outlet (red dot) is added on a stream (black); B) A new stream link (red) is added to the stream link grid, and the original link (black) is adjusted.*

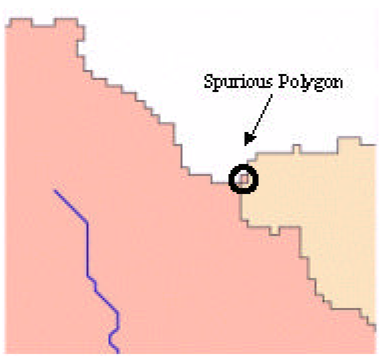
The drainage areas may now be delineated through the use of the *Watershed* function in ArcGIS. This function uses the flow direction and outlet grids to determine all of the cells that drain to each outlet. It assigns each of these cells the value of the of the outlet cell (which also corresponds to the values for the cells in the stream link grid). The delineation results are stored in a watershed grid.



*Delineated Edge Catchments*

To this point, all of the data has been in raster format. For further processing, the streams and watersheds are vectorized based on the grid value fields. The grid value is transferred to the GridCode of the corresponding vector object. Similarly, the vector representation of a delineated catchment has a gridcode attribute equal to the value of the catchment grid cells.

In the vectorization of catchments and watersheds, a complication arises through the creation of spurious polygons. Due to the regular, gridded form of the raster data, irregularly shaped watershed borders often consist of grid cells connected through the cell corners. When vectorized, these cells may become isolated from the main watershed, forming spurious polygons.




*Spurious polygon created during vectorization*

These polygons will be vectorized as distinct drainages, thereby yielding an artificially high number of drainages in an area. The ArcGIS GeoProcessing Wizard can be used to detect the existence of such polygons, and eliminate them by “dissolving” them into the surrounding polygon.

** The following text and pictures is taken directly from Furnans and Olivera (2001)

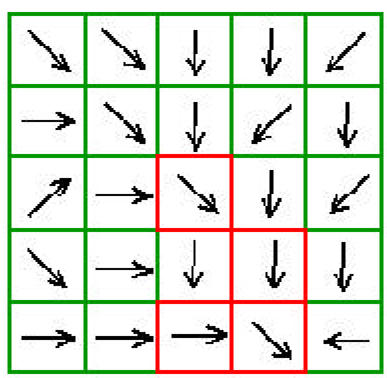
## Defining Area-to-Reach Catchments using the Hydro Network

Appendix_A describes a raster-based method of drainage delineation where synthetic streams and their corresponding catchments are created from the raster grid. An alternative approach is to take a vector Hydro Network and build the Catchments around its Hydro Edges without creating any synthetic streams. This could be called the network-based drainage delineation procedure.

Drainage delineation with a Hydro Network uses many of the same techniques as the solely elevation-based method, but rather than locating streams by a certain flow accumulation, the stream locations are fixed by the Hydro Network. This process, as described below, reduces delineation error by assuming great accuracy of the Hydro Network. This assumption is often justified, especially if the Hydro Network is derived from aerial photogrammetry.

Delineation with a given Hydro Network involves converting the network into drainage paths that may be used collectively as the streamlink grid. The drainage areas delineated with this grid are the drainage areas of each segment in the Hydro Network. It is also possible to use the Hydro Network to modify the DEM data so that the grid cells containing the known hydro network have flow accumulations large enough to be recognized as drainage paths. This process is referred to as "burning in the streams." Through this procedure, the DEM grid is modified to force waterflow into the established Hydro Network. The key to understanding this method is the realization that individual elevation values in the DEM may be uniformly changed without altering the resulting delineation.

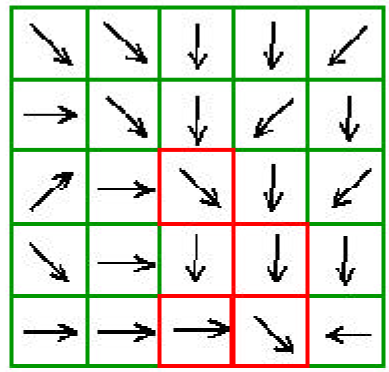
| | | | | |
|---|---|---|---|---|
| 67 | 56 | 49 | 46 | 50 |
| 53 | 44 | 37 | 38 | 48 |
| 58 | 55 | 22 | 31 | 24 |
| 61 | 47 | 21 | 16 | 19 |
| 53 | 34 | 12 | 11 | 12 |



*DEM and Flow Direction grids with stream cells highlighted (red)*

The DEM and Flow Direction grids shown here are identical to those used in the previous section, except certain cells are highlighted in red. These cells correspond to the stream cells determined from the flow accumulation grid with a 5-cell stream threshold. The same grids are now shown again, except that the elevation of each of the "non-stream" cells is increased by 100.

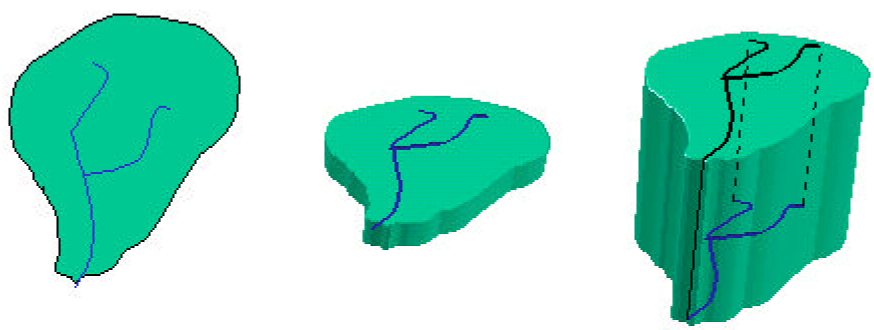
| | | | | |
|---|---|---|---|---|
| 167 | 156 | 149 | 149 | 150 |
| 153 | 144 | 137 | 138 | 148 |
| 158 | 155 | 22 | 131 | 124 |
| 161 | 147 | 121 | 16 | 191 |
| 153 | 134 | 12 | 11 | 120 |



*Burned DEM and Flow Direction grids with stream cells highlighted (red)*

In this example, all but the known stream cells were raised by an arbitrary amount. The result is that the stream cells form a trench in the DEM. Water is made to flow into this trench and down the stream network to the outlet. The phrase "burning in the streams" is appropriate because the streams have been forced, or "burned" into the topography described by the DEM. This new DEM is referred to as a *Burned DEM.*

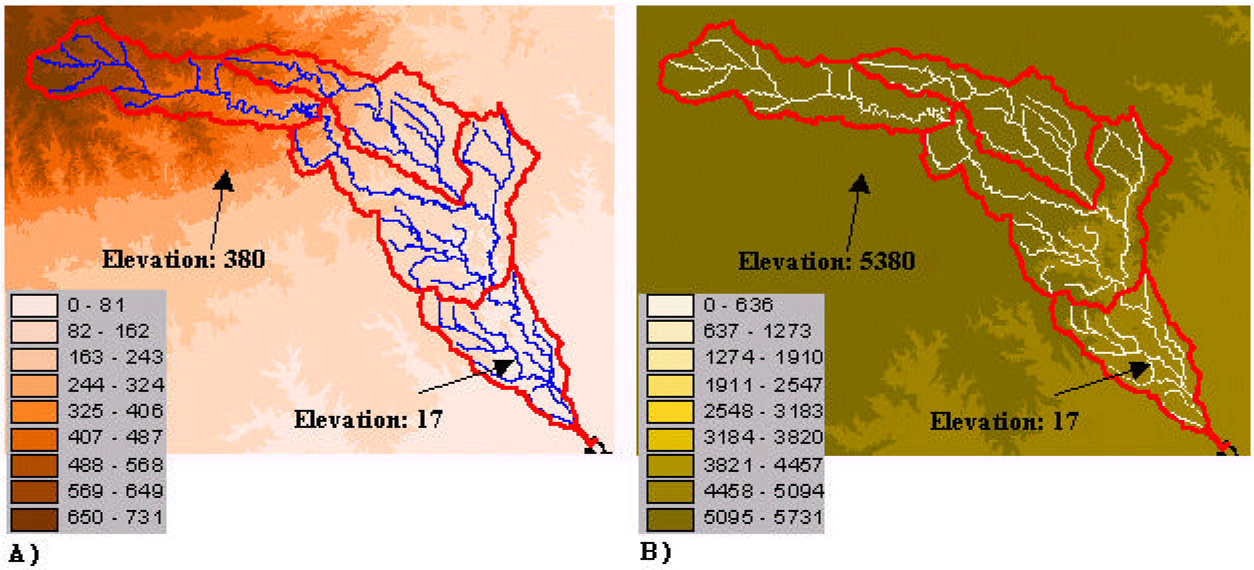
As shown, the flow direction grid derived from the burned DEM is identical to that from the original DEM. This is because the flow direction is partly determined by the relative difference in cell elevations, which is unaltered by the uniform elevation increase. Only the slopes calculated for those cells adjacent to the non-raised stream cells will be altered, and these new slopes are sufficiently large to assure flow into the stream cells.




*Burning in the Streams – Adjusting the DEM to form a trench (black) surrounding the stream network (blue)*

In order to use a Hydro Network to create burned DEMs, the vector network is converted to a grid, and this network grid is intersected with the DEM. Cells in the DEM that correspond to cells in the network grid remain unaltered while all of the other cells in the DEM are raised. The increase in elevation is arbitrary, except that it must be greater than the highest elevation in the unaltered DEM. This assures that flow in the "trenches" remains in the "trenches" until the downstream outlet is reached. Once the network is burned into the DEM, the delineation process continues as before.

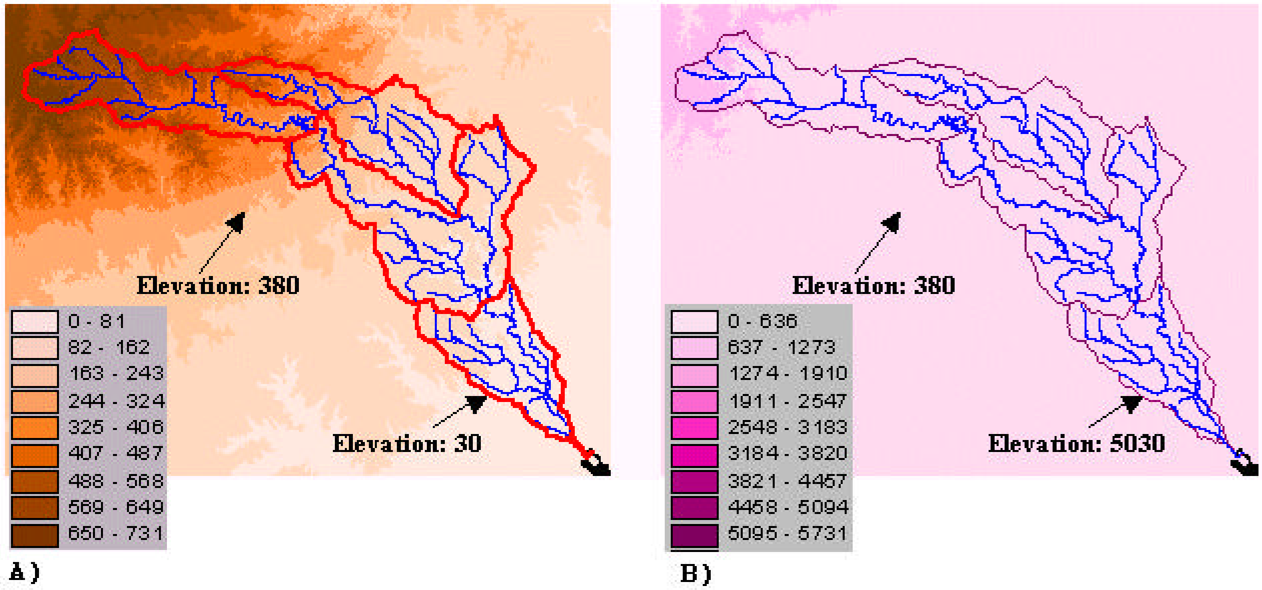
The results of the DEM-burning process are shown below for the Guadalupe Basin in Texas. The stream network was extracted from the Reach File 1 dataset, and the DEM cells are 500m in length. The burned DEM, shown in *B)*, was created from the original DEM and stream network in *A)* by raising the elevation by 5000 units. The white lines in *B)* are formed from the burned DEM cells corresponding to the stream network. It should be noted that the burned DEM does not appear as detailed as the original DEM. This is a result of the burning process, which increases the range of elevation values displayed, and thereby increases the elevation range of each color in the legend.




*Burning in the Guadalupe Basin Hydro Network – A) Basin with Hydro Network displayed; B) Burned DEM; Basin boundary (red) displayed as a reference.*

Examples of the network burning process are given in the application chapters of this book.

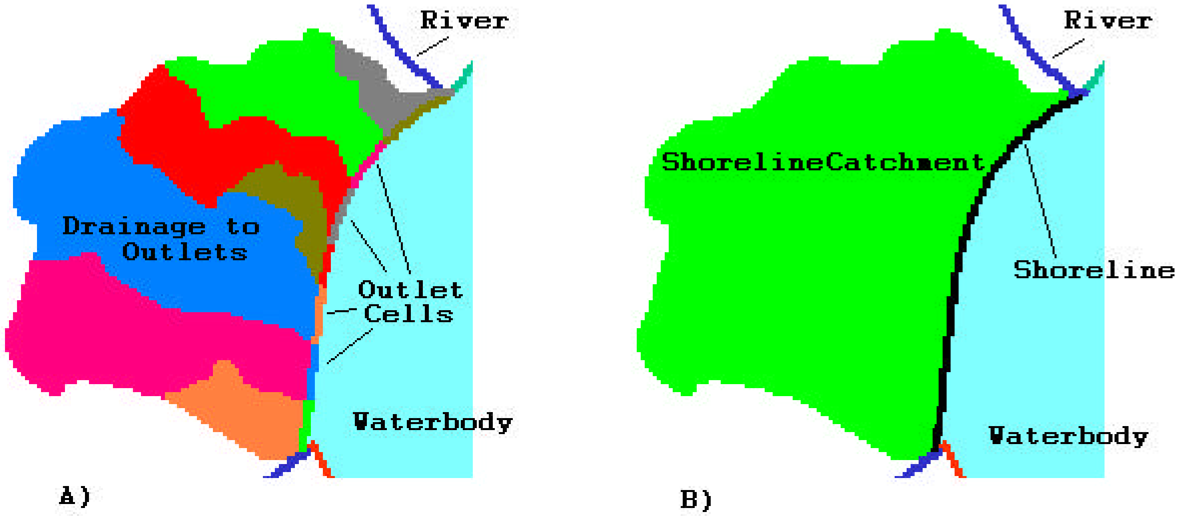
A similar process of DEM alteration can be employed if known drainage boundaries are to be incorporated into the DEM. Such a situation may arise if the DEM is of too low resolution to describe local drainage barriers such as berms or elevated highways. This process, referred to as *Building Walls*, involves raising the elevation of a connected set of DEM cells in order to prevent flow into the cells. Essentially, this is the opposite of the network burning process, for here the cells corresponding to the known boundary are elevated while all of the other DEM cells retain their original values. An example of this process as applied to the City of Austin is given in Chapter 10. The figure depicts the building of walls about the border of the Guadalupe Basin discussed previously. The boundary walls, shown in *B)*, were created from the original DEM and basin boundary in *A)* by raising the boundary elevations by 5000 units




*Building walls around the Guadalupe Basin – Hydro Network (blue) displayed as a reference*

A variation to the previously discussed delineation techniques has been developed in order to delineate Shoreline Catchments. One complication associated with this Catchment type is that unlike Flowline Hydro Edges, Shoreline Hydro Edges do not have an outlet at one end to which flow is passed along the edge length. In a physical sense, flow is transferred from the catchment across the Shoreline Hydro Edge to the waterbody, instead of being transferred along the length of the Hydro Edge. Also, flow is not transferred from the waterbody to the Hydro Edge. This distinquishes Shorelines from Flowlines in that the latter may receive flow from either side. The previously discussed delineation method does not allow for these constraints, unless modifications are made to the grids involved.

The key modification is to consider the entire Shoreline Hydro Edge as an outlet through which water drains from the Catchment to the waterbody. In raster format, each of the grid cells making up the Shoreline Hydro Edge is considered as a separate outlet cell. These cells are connected through a common GridCode attribute, which identifies the cell as part of the Hydro Edge in question. The drainage areas to each outlet cell are determined by the previously established methods, and the grid cells in each of these drainage areas contain the common GridCode attribute. The Catchment is then determined from the aggregation of all cells containing the GridCode of the Hydro Edge.




*Conceptual Representation of Shoreline Catchment Delineation – A) Shoreline Hydro Edge in raster format, each cell as an outlet. B) Aggregated drainages to outlets form the Shoreline Catchment.*

The DEM used in the delineation process assigns elevation values to cells corresponding to the waterbody, and as such it incorporates these cells in the delineation process. In order to eliminate these cells from the process, it is necessary to change their elevation values to NODATA. This is accomplished with the *IsNull* function in ArcGIS. The DEM cells corresponding to the waterbody are identified by rasterizing the vector waterbody and then intersecting the waterbody grid with the DEM. This process is described fully in Chapter 11.

The delineation process just described for Shoreline Catchments is equally valid for determining Flowline Catchments. The only difference between the two processes is the conversion of waterbody cells to NODATA cells in the DEM. for Shoreline Catchment delineation.

# Lavaca Bay, TX - Polygon and Arc Themes Metadata

**Summary:**

The *waterbodies.shp* data layer is an ArcView shapefile created from parts of the National Hydrography Dataset (NHD) and temporary polygon themes. The NHD part of the theme is identical to that used in the *withislands.shp* theme. Temporary themes were created that span the spatial extent of each island within the Bay. The *withislands.shp* theme and the temporary polygon themes were then merged using the ArcView Geoporcessing extension. The merged files were then dissolved based on a common attribute, and the result is a single continuous polygon of the Lavaca-Matagorda Bay area.

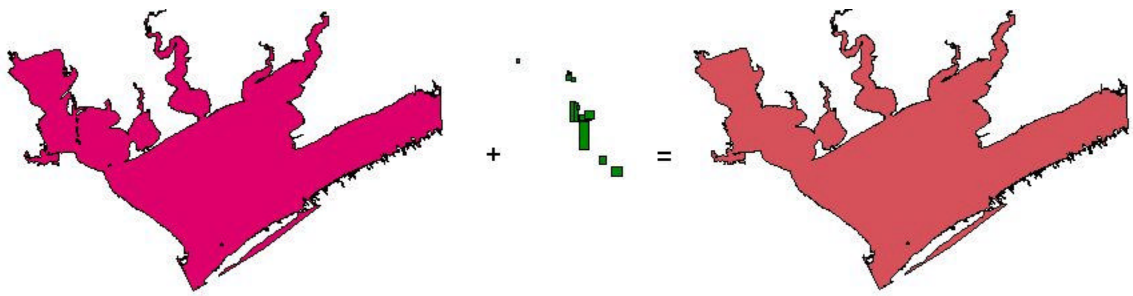



*Figure C-1 – Merging themes to create a single waterbodies polygon*

The *withislands.shp* data layer is an ArcView shapefile created from the National Hydrography Dataset (NHD). This data layer covers the entire extent of Lavaca Bay, and includes the section of Matagorda Bay that will be modeled in ELCOM. This theme includes various islands within the Bay, just as they exist in the NHD and on maps. The existence of these islands makes the Bay geometry more complex, and will likely greatly affect flow patterns within the Bay. To create a less complex description of the Bay, the islands were removed in the *Lavaca.shp* data layer.

The *Lavaca.shp* data layer is an ArcView shapefile created from parts of the National Hydrography Dataset (NHD) and the temporary polygon themes. The NHD part of the theme is identical to that used in the *withislands.shp* theme, except that Matagorda Bay is not included. Temporary polygon themes were created that span the spatial extent of each island within the Bay (See Figure C-1). The *withislands.shp* theme and the temporary polygon themes were then merged using the ArcView Geoporcessing extension. The merged files were then dissolved based on a common attribute, and the result is a single continuous polygon of the Lavaca Bay area.

Sounding data in the *bath_points.shp* theme, derived from the GEODAS data, do not indicate the existence of the Bay ship channel or the islands. This suggests that the sounding points were taken before the ship channel was dredged, the spoils from which formed many of the islands. The bathymetry data available here must be updated with more accurate and recent measurements.

The *segments.shp* data layer is an ArcView shapefile created from the National Hydrography Dataset (NHD). This theme was created by converting the *waterbodies.shp* polygon theme into an arc theme using the ArcGIS/ArcInfo functionalities. The resulting waterbody outline was then dissolved into a single arc, and then split into multiple segments based on the intersection of the *toburn.shp* river network theme. The result is that the entire waterbody outline was divided into shoreline reaches separated by rivers that enter Lavaca Bay. This theme was used to make the "source_grid" for the delineation of watersheds draining to Lavaca Bay.

The *barriers.shp* data layer is an ArcView shapefile created from the National Hydrography Dataset (NHD). This theme was created by converting the *withislands.shp* polygon theme into an arc theme using the ArcGIS/ArcInfo functionalities. This theme could be used as a barrier theme in the baythmetry interpolation process in ArcView. If so, the resultant bay bathymetry would include the islands and possible a more accurate description of the bathymetry near the Lavaca Bay shores. These ideas are described fully in the *Task E* report.

All layers were created at the Center for Research in Water Resources from March, 2001 to August 2001.

**Map projection:** Texas Centric Mapping System Albers Equal Area (TCMS AEA)

```
Projection   ALBERS
Datum        NAD83
Zunits       NO
Units        METERS
Spheroid     GRS1980
Xshift       0.0000000000
Yshift       0.0000000000
Parameters
 27 30  0.000 /* 1st standard parallel
 35  0  0.000 /* 2nd standard parallel
-100  0  0.000 /* central meridian
 18  0  0.000 /* latitude of projection's origin
1500000.00000 /* false easting (meters)
6000000.00000 /* false northing (meters)
```

**Creation date**: March 2001 to August 2001
**Created by:** Jordan Furnans (jfurnans@mail.utexas.edu)
Center for Research in Water Resources (CRWR)
**Created for:** Texas Natural Resources Conservation Commission (TNRCC)
Total Maximum Daily Load (TMDL) Program
Contract No. 582-0-80114

# Sample Files from ELCOM, GIS

## Sample Bathymetry File for ELCOM

(Section of 250m_channel.txt created by the ***Bathymetry.exe*** program)

```
FILE       250m_channel.txt
 VERSION    1.1.a
! ---------------------------------------------------------------------- !
'Lavaca Bay 250m - 1st Try with Channel'             TITLE
 'Jordan Furnans'                      ANALYST
 'CRWR'   ORGANIZATION
 'August 9, 2001'                      COMMENT
! ---------------------------------------------------------------------- !
 yes         overwrite files
! ---------------------------------------------------------------------- !
! number of grid cells                                                  !
! -                                                             !
  89    x_rows
 96    y_columns
 10          z_layers
  0          n_max
! ---------------------------------------------------------------------- !
! land and open boundary bathymetry values                                       !
! -                                                             !
 9999      land_value
 8888      open_value
! ---------------------------------------------------------------------- !
! geographic position                                                   !
! -                                                             !
  -4.0                  north_x (positive x towards bottom of page)
   2.0                  north_y (positive y towards right on line)
 28.0                   latitude
   -96.0                longitude
   0.0                  altitude
! ---------------------------------------------------------------------- !
! grid spacing                                                        !
! -                                                             !
 250      x_grid_size
 250      y_grid_size
!                                                        !
! ----------------------------------------------------------------- !
! - dz vector starting from top going down                              !
!                                                        !
 0.715     dz top
 0.715     dz
 0.715     dz
 0.715     dz
 0.715     dz
 0.715     dz
 0.715     dz
 0.715     dz
 0.715     dz
 0.715     dz bottom
! ---------------------------------------------------------------------- !
! x in rows (increasing down), y in columns (increasing across)           !
 BATHYMETRY DATA
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 -0.9343436 -0.8062027 -0.4059184 -0.8874688 -0.9 9999 99
9999 9999 -0.3093643 -0.288461 -0.2859574 -0.2859605 9999 9999 9999 9999 9999 9999 9999 9999
```

# Sample Exported GIS Bathymetry Grid

(Section of 250m_channel.asc used in the ***Bathymetry.exe*** program)

```
ncols         96
nrows         89
xllcorner     1825214.78276
yllcorner     7161459.095
cellsize      250
NODATA_value  -9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
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9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 -0.9343436 -0.8062027 -0.4059184 -0.8874688 -0.9 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
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9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 -0.9 -0.7950913 -0.7273785 -1.058057 -0.9098277 -0.9103356 -0.9057034 -0.9 -
0.9115488 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 -0.289701 9999 9999 -0.2883721 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 -0.7582029 -0.7314861 -0.8683853 -0.9 -0.9021916 -1.066389 -1.163307 -1.187572 -
1.193856 -1.18399 -1.183584 -0.9045614 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 -0.3093643 -0.288461 -0.2859574 -0.2859605 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 -0.9252622 -1.042692 -0.9590374 -0.918718 -0.8899049 -0.8493605 -0.9 -0.9083706 -1.087612 -
1.190854 -1.2 -1.2 -1.2 -1.188507 -1.167756 -0.9670988 -0.7188566 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 -0.3066112 -0.2834055 -0.2761165 -0.2930393 9999 9999 9999 9999 9999 9999 9999 -
0.729126 -0.7566124 -0.6237453 -1.05103 -1.140373 -0.9424687 -1.077871 -0.9192443 -0.9 -0.9124597 -
1.128757 -1.19086 -1.2 -1.2 -1.2 -1.2 -1.19079 -1.011927 -1.084227 -0.8711203 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999 9999
```

# Sample User-Defined Input File

(250m_channel_input.txt used in the ***Bathymetry.exe*** program)

```
'Lavaca Bay 250m - 1st Try with Channel'        TITLE
 'Jordan Furnans'                ANALYST
 'CRWR'   ORGANIZATION
 'August 9, 2001'                COMMENT
 yes      overwrite files
 14       z_layers
  0       n_max
 9999     land_value
 8888     open_value
  -4.0             north_x (positive x towards bottom of page)
   2.0             north_y (positive y towards right on line)
 28.0              latitude
   -96.0           longitude
   0.0             altitude
 0.715    dz top
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz
 0.715    dz bottom
! ------------------------------------------------------------------------- !
! x in rows (increasing down), y in columns (increasing across)           !
 BATHYMETRY DATA
```

Appendix F

## SUMMARY OF EDITS

The edits made on January 15, 2002 were in response to comments from Sandra A. Alvarado of the TNRCC. These comments are given in *italics* below, and are followed by a summary of the changes made to the original text in order to accommodate the comments. The change summary is given in regular typeset and is indented.

Introduction

*1. TMDLs address point and nonpoint sources of pollution as well as background levels. Both point and nonpoint sources are potential sources of pollution contributing to the dissolved oxygen and mercury impairments in Lavaca Bay. Dredge Island is suspected to be the "primary source" of mercury to Lavaca Bay, but others such as stormwater, atmospheric, and/or nonpoint runoff are also potential sources not yet assessed. The report states that "...hypoxia is likely due to nonpoint source pollution...", however some point sources such as permitted wastewater discharges may also contribute to hypoxia. Other potential causes of hypoxia include subdued mixing and reaeration. Please incorporate language that reflects these other potential sources of pollution.*

> On page 4, the phrase “main source of” has been included in order to imply that the specified pollution sources are not necessarily the only pollution sources contributing to the Lavaca Bay system.

*2. Bottom of page 4, the following sentence reads "This database contains information related to the expectant..." The word "expectant" seems out of place, perhaps "expected" would be more appropriate.*

> On page 4, the word “expectant” was replaced with “expected.”

Part 1

*3. Page 6, last paragraph refers to the "...upper left corner of the tile..." Is this the same as the northwest corner? Please clarify.*

> On page 6, the word “Northwest” was included to clarify the point that DEM tiles are named based on the latitude and longitude of their Northwest (upper left) corner.

*4. Fig. 10 - It is unclear what the differences are between wtrshd1.shp and wtrshd2.shp. Please provide some clarification. The following is my interpretation of what the differences are but I am not certain: wtrshd1.shp includes subwatersheds within the Lavaca Bay watershed and wtrshd2.shp distinguishes the Lavaca Bay watershed from the Matagorda Bay watershed.*

> On pages 13 and 14, text was added to clarify the contents of the wtrshd1.shp and wtrshd2.shp themes. The interpretation in the above comment is correct.

*5. Please explain how the 100m buffer for the study area shape file was derived and why. Is this around the edge or to elevations?*

On page 14, text was added to clarify how and for what purpose the 100m buffer was created. This buffer is created around the edge of the study area and does not affect the DEM elevations in any way.

Part 2

*6. Why was ELCOM chosen? Was consideration given to other 3-D hydrodynamic models?*

On page 15, text was added to clarify why the ELCOM model was chosen for use on this project over other 3-dimensional hydrodynamic models.

*7. Pg. 18 makes reference to Fig. 12, but I believe the intent is to refer to Fig. 13.*

On page 18, the figure number was corrected. It should reference Fig. 13, not Fig. 12.

*8. Data source for ship channel is weak. The US Army Corps of Engineers has location data for the ship channels. Also check with TNRIS and/or GLO.*

On page 18, text was added to clarify why more accurate ship channel data was not incorporated into the model. Text was also added on page 33 indicating that future studies would require accurate ship channel data.

*9. Pg. 22 in the second paragraph I suggest the replacement of the word "importance" with "effect".*

On page 22, the word “importance” was replaced by “effect.”

*10. Pg. 23, last sentence should read "The effects...", not affects.*

On page 23, the word “affects” was replaced by “effects.”

*11. Could the effect of the Lavaca River inflow been better characterized had the following scenario been simulated: 250m bathymetry, with Lavaca River inflow, without ship channel?*

On page 31, text was added to discuss why such a simulation was not carried out.

*12. Should the inflow from Cox Creek and Huisache Creek be considered in the model? Not sure what the flow is like in this area, but according to Figure 8, they both show up in the DEM which is some indication that they have some significant flow.*

On page 31, text was added describing why streams such as Cox Creek and Huisache Creek were not included in this preliminary modeling effort. Their inclusion in Figure 8 only suggests that a stream exists in their location if sufficient runoff is present.

*13. Pg. 30, Preliminary Modeling Conclusions - other things to consider discussing in this section include the data needs, if different from what's presented, to address sediment/water flux and assimilative capacity of bay water with regards to the constituents of concern.*

> This comment was not addressed specifically in the text, although the "Future Modeling Efforts" section describes some of the data that would be required for more accurate TMDL modeling.

*14. Pg. 30, does "outside the channel" refer to: a) zone above channel cut within a cell over the channel, or b) cells that are not over the channel?*

> On page 30, the phrase "outside of" was replaced by the word "above." The reference is to the water in the water column over the ship channel but extending from the water surface to the bottom of the bay if the ship channel were not present.

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